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STEAM BOILERS

TERRELL CROFT, Editor

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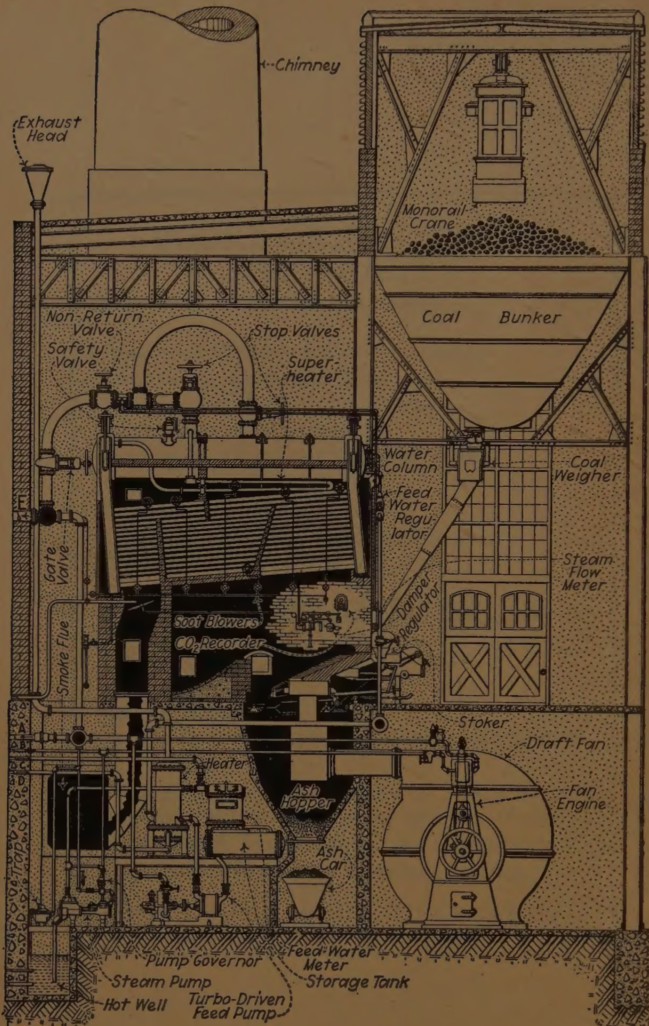

FRONTISPIECE.—Equipment in a modern boiler plant as suggested by "Power." (A = Steam supply pipe to engine-room auxiliaries. B = Exhaust pipe from boiler-room auxiliaries running to exhaust header in engine room. C = Discharge pipe from condensate pump in engine room. D = Pipe draining exhaust header in engine room. E = Main steam pipe to engine room. The pump which is labeled "Steam Pump" in the above illustration is the *hot-well pump*.)

STEAM BOILERS

TERRELL CROFT, Editor

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MEMBER OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.
MEMBER OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.
MEMBER OF THE ILLUMINATING ENGINEERING SOCIETY.
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First Edition
Third Impression

McGRAW-HILL BOOK COMPANY, Inc.
NEW YORK: 370 SEVENTH AVENUE
LONDON: 6 & 8 BOUVERIE ST., E. C. 4

PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS - YORK PA

PREFACE

Steam Boilers has been prepared primarily for men of little schooling who desire to acquaint themselves regarding this subject. A working knowledge of arithmetic will qualify one to read it understandingly. But, since all of its statements and the methods and principles which it proposes are both theoretically and practically sound, it may be used effectively by any one, regardless of his training or experience, who seeks steam-boiler information. It has been written with the special intent of serving the needs of those who are preparing to pass engineers'-license examinations.

Drawings for all of the 514 illustrations were made especially for this work. It has been the endeavor to so design and render these pictures that they will convey the desired information with a minimum of supplementary discussion.

Throughout the text, principles which are presented are explained with descriptive expositions or with worked-out arithmetical examples. At the end of each of the 25 divisions there are questions to be answered and, where justified, problems to be solved by the reader. These questions and problems are based on the text matter in the Division just preceding. If the reader can answer the questions and solve the problems, he then must be conversant with the subject matter of the Division. Detail solutions to all of the problems are printed in an appendix in the back of the book.

As to the general method of treatment:—First, the functions, the history and the modern types of boilers are considered. Then boiler codes and inspection laws are discussed. Next, the elements of modern boiler construction, in accordance with The American Society of Mechanical Engineer's Boiler Code, is presented under such Division titles as:—Boiler stresses and strengths, riveted joints, braces and stays, fire tubes and water tubes, manholes and handholes—and the like.

This is followed by matter relating to:—Boiler accessories, steam generation and super-heating, and boiler capacities and ratings.

Continuing: the matter which concerns boiler-room economy is introduced under such headings as:—Fuels, draft and its production and measurement, combustion and firing, boiler settings and furnaces, mechanical stokers, petroleum and gaseous fuels, chimneys breechings and dampers, artificial draft equipment, fuel economizers, feed water and feed-water treatment—and steam-boiler management inspection and maintenance.

Finally, the selection of steam boilers is given attention.

With this, as with the other books which have been prepared by the author, it is the sincere desire to render it of maximum usefulness to the reader. It is the intention to improve the book each time it is revised and to enlarge it as conditions may demand. If these things are to be accomplished most effectively, it is essential that the readers coöperate with us. This they may do by advising the author of alterations which they feel it would be desirable to make. Future revisions and additions will, insofar as is feasible, be based on such suggestions and criticisms from the readers.

Although the proofs have been read and checked very carefully by a number of persons, it is possible that some undiscovered errors may remain. Readers will confer a decided favor in advising the author of any such.

TERRELL CROFT.

UNIVERSITY CITY,
ST. LOUIS, MO.,
May, 1921.

ACKNOWLEDGMENTS

The author desires to acknowledge the assistance which has been rendered by a number of concerns and individuals in the preparation of this book.

Considerable of the text material appeared originally as articles in certain trade and technical periodicals among which are: *Power*, *National Engineer*, *Power Plant Engineering*, *Southern Engineer*, and *Combustion*.

Among the concerns which coöperated in supplying text data and copy for illustrations are: *Freeman & Sons Manufacturing Company*, boiler manufacturers; *Murray Iron Works Company; Babcock & Wilcox Company; Heine Boiler Company; Westinghouse Machine Company; Riley Stoker Company; Taylor Stoker Company; Stirling Boiler Company; Page Burton Boiler Company; Riehle Testing-Machine Company; Ashton Valve Company; Crosby Steam Gage & Valve Company; Penberthy Injector Company; Ohio Brass Company; Precision Instrument Company; Kewanee Boiler Company; American Blower Company; B. F. Sturtevant Company; Green Fuel Economizer Company; Edgemoor Boiler Company; Smooth-On Manufacturing Company.*

Special acknowledgment is accorded to the *American Society of Mechanical Engineers* for permission to incorporate herein certain tables and other material from the A. S. M. E. Boiler Code. Also, acknowledgment is accorded to *The Hartford Boiler Insurance Company* for the use of data from certain of its publications.

Certain material in the text has also been taken from the following sources: Steam—Its Generation and Use, by the Babcock and Wilcox Company; University of Illinois Bulletin No. 31, "Fuel Economy in the Operation of Hand-fired Power Plants." Engine-cylinder drawings in the division on Stresses and Strains were taken from articles by F. R. Low in *Power*. The chronology of power-plant apparatus is due to Chas. J. Mason in *National Engineer*, April, 1914.

Other acknowledgments have been made throughout the book. If any has been omitted, it has been through oversight and if brought to the author's attention it will be incorporated in the next edition.

Terrell Croft.

CONTENTS

STEAM BOILERS

List of Symbols

The following list comprises practically all of the symbols which are used in formulas in this book. Symbols which are not given in this list are defined in the text where they are first used. When any symbol is used with a meaning different from that specified below, the correct meaning is stated in the text where the symbol occurs.

Symbol	Meaning	Section first used
A	Area, in square inches	232
A	Cross-sectional flue area of chimney, in square feet	492
A_d	Cross-sectional area of diagonal stay, in square inches	245
$A.D.P.D._{BC}$	Available-draft-pressure drop through boiler and breeching to smoke-conduit connection, in inches water column	490
A_t	Cross-sectional area of a through-stay, in square inches	245
$B.t.u.$	British thermal unit	402
c	Distance from axis of moments to extreme fiber	523
d	Diameter of chimney flue, in feet	492
d	Internal diameter of shell, in inches	185
D	Diameter of rivet holes, in inches	219
d_i	Internal diameter of tube, in inches	165
d_i	Inside diameter of chimney, in inches	530
d_o	Outside diameter of chimney, in inches	530
E	Efficiency	207
$E.D.P.$	Effective draft pressure, in inches water column	490
f	Factor of safety	189
F	Total force due to wind, in pounds	515
FS	Factor of safety	207
I	Moment of inertia	523
k	A constant	246
L	Internal length of shell, in inches	185
L_d	Length of diagonal stay, in inches	245
L_D	Horizontal distance, in inches, from fulcrum to center of gravity of valve disc	291
L_h	Distance, in inches	244
L_h	Height of chimney, in feet	481
L_{hc}	Height of center of gravity of projected area of chimney, in feet	517

Symbol	Meaning	Section first used
L_{hc}	Distance, in feet	527
L_L	Horizontal distance, in inches, from fulcrum to center of gravity of lever	291
L_P	Distance from surface supported to center of palm of diagonal stay	245
L_p	Pitch of stays, in inches	246
L_t	Thickness, in inches	165
L_W	Horizontal distance, in inches, from fulcrum to ball	291
L_w	Width, in inches	243
L_{wb}	Width of chimney base, in feet	515
L_{wt}	Width of top of chimney, in feet	515
L_U	Width of strip, in inches	230
N	Number of rivets in unit strip	232
P	Pressure, in pounds per square inch	165
P	Pitch of rivets, in inches	218
P	Wind pressure, in pounds per square foot	517
P_2	Atmospheric pressure at altitude of chimney, in pounds per square inch	481
P_B	Steam pressure on boiler, in pounds per square inch	283
P_{bl}	Longitudinal bursting pressure, in pounds per square inch	203
P_{bt}	Transverse internal bursting pressure, in pounds per square inch	195
p_c	Total maximum pressure, in pounds per square inch	524
p'_c	Pressure, in tons per square foot	521
p'_c	Pressure, in pounds per square inch, due to dead weight of chimney	524
p''_c	Maximum compressive stress, in pounds per square inch	523
P''_c	Maximum stress in chimney wall, in pounds per square inch due to wind	531
P'_c	Compressive stress, in pounds per square inch	530
P'''_c	Stress, in pounds per square inch	533
P'_D	Total draft pressure, in inches water column, at base of chimney	481
P''_D	Total draft pressure which chimney must develop, in inches water column	490
P_{gl}	Internal pressure on shell, in pounds per square inch	198
P_{gt}	Internal pressure, in pounds per square inch, gage	185
P_L	Total longitudinal pressure, in pounds, on head of shell	198
P_{MAW}	Maximum allowable working pressure, in pounds per square inch	207
P_T	Total pressure, in pounds, tending to rupture shell	185
r	Internal radius of shell, in inches	186

Symbol	Meaning	Section first used
R	Inside radius of shell, in inches	207
S_c	Unit crushing strength, in pounds per square inch	233
$\mathbf{S}_c$	Total crushing strength of rivet or plate, in pounds	233
$\mathbf{S}_s$	Shearing strength in single shear, in pounds	232
S_s	Unit shearing strength of rivet, in pounds per square inch	232
$\mathbf{S}_T$	Tensile strength of unit strip, in pounds	230
S_T	Unit tensile strength, in pounds per square inch	230
$\mathbf{S}'_T$	Tensile strength of plate between rivet holes, in pounds	231
S_{Tt}	Safe resisting strength against internal transverse bursting pressure, in pounds	189
S_T^l	Safe resisting strength against longitudinal pressure, in pounds	200
t	Minimum thickness of shell plate, in inches	207
T_G	Average temperature of chimney gases, in deg. fahr.	481
T_0	Temperature of outside air, in deg. fahr	481
TS	Ultimate tensile strength of boiler plate as stamped on shell, in pounds per square inch	207
U_t	Ultimate tensile strength, in pounds per square inch	189
v	Velocity, in miles per hour	513
$\mathbf{W}$	Weight, in pounds	527
$\mathbf{W}_c$	Coal burned per hour, in pounds	492
$\mathbf{W}_D$	Weight of valve disc and stem, in pounds	291
$\mathbf{W}_L$	Weight of lever, in pounds	291
$\mathbf{W}_t$	Weight of stack and foundation, in tons	521
$\mathbf{W}_W$	Weight of ball, in pounds	291
x	Distance, in feet	527

DIVISION 1

FUNCTION, CLASSIFICATIONS AND REQUIREMENTS OF THE STEAM BOILER

1. The Function Of The Steam Boiler (Fig. 1) is to convert and transfer the chemical energy in the fuel which is burned, to heat energy in the steam, and thus render it available for use in heating systems and for conversion into mechanical energy by engines. The fuel may be of fossil origin, such as coal, peat, or petroleum. Or it may be one such as wood, straw, or bagasse, derived recently from forest or field. (See the author's PRACTICAL HEAT.)

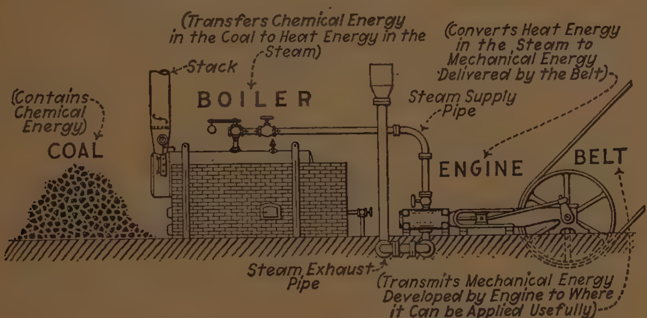


FIG. 1.—Illustrating the function of the steam boiler.

NOTE.—As is explained in the author's PRACTICAL HEAT, the chemical energy in the fuels was imparted to them by the sun.

NOTE.—Thurston says: "The office of the steam boiler is to transfer the heat energy produced by the combustion of the fuel to the mass of enclosed water and by the conversion of the latter into steam to store that energy in available form for use, as in the steam engine."

2. The Definition Of A Steam Boiler Is A closed vessel in which, by the application of heat, water is boiled and thereby converted into steam, which is then available for power or heating.

3. The Possible Classifications Of Steam Boilers are numerous, since the various types and designs may be grouped

in accordance with any one of a number of different schemes and plans. Thus, they may be classified as to design, construction, method of firing, arrangement of tubes, application, and so on.

4. A Classification Of Modern Boilers Into Externally-fired and internally-fired is probably the most practical for purposes of general discussion. In this book the boilers of the different types are, in general, considered in accordance with this classification, but no effort has been made to adhere rigidly to it. The classification follows:—

I—Externally-fired.

- (1) Plain cylindrical (Figs. 25, 29).
- (2) Return-flue (Figs. 33, 34, 35).
- (3) Return-tube or multi-tubular (Figs. 36, 37, 38, 39).
- (4) Water-tube.
  - (*a*) *Horizontally-inclined-tube sectional* ((*Figs.* 60, 61).
  - (*b*) *Horizontally-inclined-tube water-leg* (*Fig.* 67).
  - (*c*) *Vertically-inclined curved-tube* (*Fig.* 71).
  - (*d*) *Vertically-inclined straight-tube* (*Fig.* 72).
  - (*e*) *Vertical curved-tube* (*Fig.* 77).
  - (*f*) *Vertical straight-tube* (*Fig.* 78).
  - (*g*) *Pocket-tube or porcupine* (*Fig.* 79).
  - (*h*) *Coil or loop-tube* (*Figs.* 80, 81).
- (5) Combination fire-tube and water-tube (Fig. 83).
- (6) Spherical sectional (Fig. 59).

II—Internally-fired.

- (1) Cornish or single-flue (Fig. 41).
- (2) Lancashire or double-flue (Fig. 42).
- (3) Galloway or breeches flue (Figs. 43, 44, 45, 46).
- (4) Locomotive fire-box.
  - (*a*) *Mud-ring fire-box* (*Fig.* 51).
  - (*b*) *Water-bottom fire-box* (*Fig.* 52).
- (5) Vertical fire-tube.
  - (*a*) *Exposed-tube* (*Fig.* 54).
  - (*b*) *Submerged-tube* (Fig. 56).
- (6) Scotch or drum.
  - (*a*) *Dry-back* (*Fig.* 47).
  - (*b*) *Wet-back* (*Figs.* 48, 49, 50).

5. Other Steam Boiler Classifications Which are sometimes employed are:—

1. Plain cylindrical, fire-tube, water-tube, and combination fire-tube and water-tube.
2. Horizontal and vertical.
3. Stationary, locomotive, and marine.

6. The Requirements Of The Ideal Steam Boiler are listed below. It should be understood that the thirteen requirements which follow are for an "ideal" boiler. In practice it may not be possible or feasible to satisfy all of them strictly. In fact, the design of a practical boiler must be a compromise. In it all of these desirable requirements should be fulfilled insofar as is attainable at justifiable cost. When conditions merit the installation of a boiler of high cost, then the requirements may obviously be satisfied more nearly than in cases where there can be only a small expenditure for the boiler plant. Where fuel cost is low, great refinement in boiler design and the money lay-out it involves may not be sound engineering. But in any case, specifications which tend to minimize the risk to human life should be observed. The requirements are:

1. Proper workmanship and simple construction, using materials which experience has shown to be the best, thus avoiding the necessity of early repairs.
2. A mud-drum to receive the impurities deposited from the water and so placed as to be removed from the action of the fire.
3. A steam and water capacity sufficient to prevent any material fluctuation in steam pressure or water level.
4. A water surface, for the disengagement of the steam from the water, of sufficient extent to prevent priming.
5. A constant and thorough circulation of water throughout the boiler so as to maintain all parts at as nearly the same temperature as possible.
6. A form of construction which will obviate, insofar as is humanly possible, the liability of disastrous explosions.
7. A great excess of strength over any legitimate strain. The boiler should be so constructed as to be free from strains due to unequal expansion. If possible, joints exposed to the direct action of the fire should be avoided.
8. A combustion chamber so arranged that the combustion of gases started in the furnace may be completed before the gases escape to the chimney.
9. A disposition of the heating surface, relative to the direction of flow of the gases of combustion, that will insure the greatest possible transfer of heat to the water in the boiler.

10. Ready accessibility to all parts for cleaning and repairs.

11. Proportionment for the work to be done and capability of operating to its full rated capacity with the highest attainable economy.

12. An auxiliary equipment comprising the very best gages, safety valves, and other fixtures.

13. A setting that will insure maximum efficiency of combustion and that will obviate, to the highest attainable degree, losses of heat by radiation and impairment of the furnace efficiency by the infiltration of air.

NOTE.—The above requirements are based on the SPECIFIC REQUIREMENTS OF A PERFECT STEAM BOILER which was prepared by G. H. Babcock and Stephen Wilcox in 1875 and which has appeared in the several editions of the book STEAM—ITS GENERATION AND USE. However, certain of the requirements have been modified in order to render them general, rather than specific, in scope. Furthermore, requirement No. 13 has been added.

QUESTIONS ON DIVISION 1

1. State, in general terms, the function of a steam boiler.

2. How is the energy, which is made available by a boiler, principally utilized?

3. Give an example of a fossil fuel.

4. Give an example of a vegetable fuel.

5. Whence comes the energy that resides in fuels?

6. Give the conventional definition of a steam boiler.

7. What principal attributes of steam boilers determine their classification?

8. Into what two general divisions may steam boilers be conveniently separated?

9. To which of these divisions does the locomotive form of stationary boiler belong? The dry-back Scotch boiler? The return-tubular boiler?

10. What are the principal requisites to be fulfilled in the building and installation of steam boilers?

11. What considerations determine, in specific cases, the degree in which requisites of the "ideal" boiler shall be approximated?

12. What is the paramount consideration in all cases?

DIVISION 2

EVOLUTION OF THE STEAM BOILER

7. Steam Boilers Are Of Ancient Origin.—They have been used for various services and in many forms since remote times. But prior to the eighteenth century none of the devices developed had, as measured by present-day standards, any practical value. However, it is desirable to consider for a moment some of the boilers of the pioneer types so that the reader may be conversant with the evolution which has occurred.

8. The First Boilers Were Of Greek And Roman Origin, so it is believed. They were employed several hundred years prior to the Christian Era. They (Figs. 2 and 3) were small affairs, and were employed for warming water, for heating, and for household services. The boiler of Fig. 2, recovered from the ruins of Pompeii, constitutes a typical example. It was of cast bronze, and was evidently of the "internally-fired" type. The grate (Fig. 3) comprises sheet bronze tubes opening and brazed into the water leg of the boiler. From this it is evident that the water-tube principle is an old one.

NOTE.—When in use, the boiler proper was supported on an ornamental tripod (Fig. 2) which permitted the air required for combustion to enter from beneath. Three gas vents were arranged from the furnace chamber through the water leg to provide an exit for the products of combustion. The actual Pompeiian boiler was embellished with finely-wrought ornaments and miniature sculptures.

9. The Boiler Used With Hero's Engine Was The First Recorded As Doing Mechanical Work.—It was made about 130 B.C. It consisted merely of a hemispherical caldron, of ornamental design, which was heated by a lamp arranged under it.

NOTE.—Hero's engine was a hollow sphere, mounted and revolving on trunnions, having extending from it two nozzles with right-angle turns

at their ends. Steam from the boiler was admitted to the interior of the sphere through one of the trunnions. This steam, in issuing from the nozzles, caused the sphere to rotate by virtue of the same principle as that on which the reaction turbine operates.

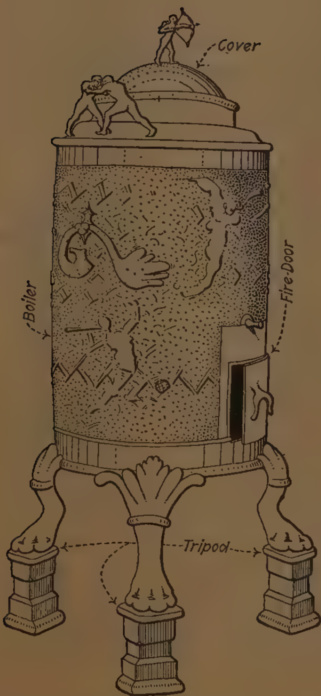


FIG. 2.—Pompeiian domestic-water heating boiler (year A. D. 79).

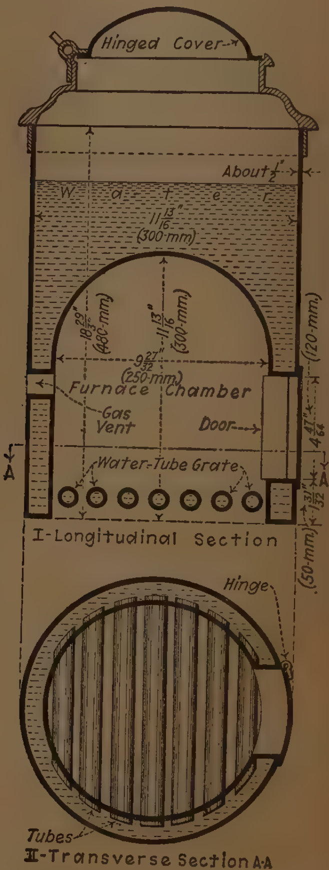


FIG. 3.—Details of the bronze Pompeiian boiler. (Legs not shown.)

10. Florence Raivault's steam bombshell (Fig. 4) was used by that experimenter in 1605 to determine the disruptive force of steam. The spherical shells consisted of hollow copper castings. They were made with walls of varying thickness. Each shell had a single orifice. The experiment

consisted in filling a shell with water, plugging the orifice, and applying heat.

11. Giovanni Branca's boiler was made about the year 1629. Branca was an Italian physicist. His invention consisted of a casting in the shape of a hollow human head and trunk. In the mouth of the figure was a nozzle. The hollow casting was filled with water and a fire was built around it. The steam, which then issued from the nozzle, impinged on a wheel having vanes around its periphery. Thus the wheel was caused to turn, and by means of gears its power was transmitted and caused to do work.

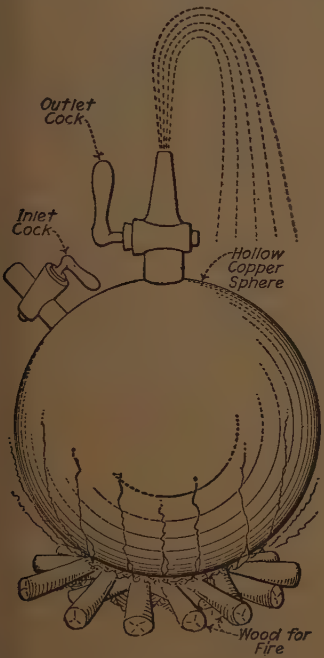


Fig. 4.—Florence Raivault's steam bombshell (year 1605).

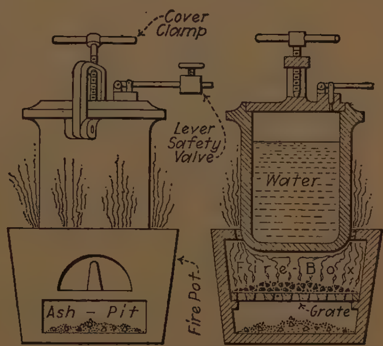


Fig. 5.—Elevation and section of Papin's boiler and safety valve (year 1680).

12. Denis Papin's Boiler (Fig. 5) was used in 1680, so it is recorded, as a "digester," or apparatus for converting the bones of cattle into a gelatine-like substance. The process required steam at a very-high temperature. To obtain the requisite degree of heat, Papin developed a steam pressure of 1,500 lb. per sq. in. He appears to have been the first to produce steam at a pressure greater than 100 lb. per sq. in. This boiler was fitted with a lever safety valve. It is asserted by some that Papin was the inventor of the safety valve.

13. Savary's boiler (Fig. 6), so named after its constructor, was made in 1698. This apparatus utilized the phenomena of both condensation and pressure for elevating water. The shell was spherical in shape. This, apparently, is the pioneer example of the application of a specially-designed setting and furnace for a steam boiler.

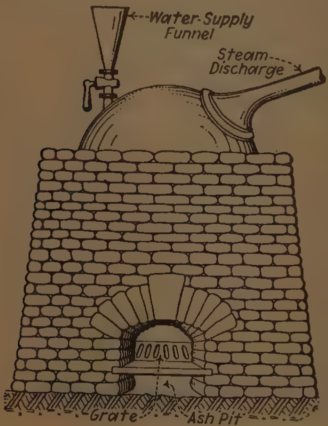


Fig. 6.—Savary's spherical boiler (year 1698).

14. Savary's improved boiler (Fig. 7) constructed in 1702, was an evolution from his original invention. In this, the boiler proper was, so it is believed, a hollow cylinder having dished ends.

15. Dr. Desagalier's spherical boiler (Fig. 8) was built in 1718. In this design the hot gases from the fire were caused to circulate in a spiral flue around a spherical water vessel.

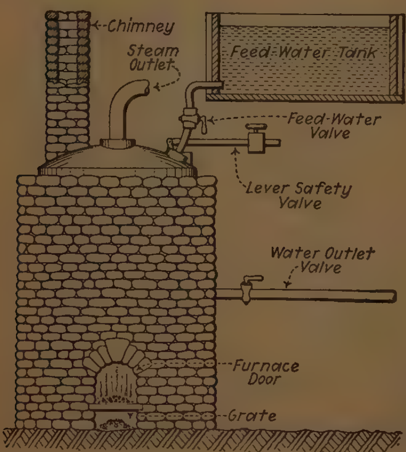


Fig. 7.—Savary's improved boiler (year 1702).

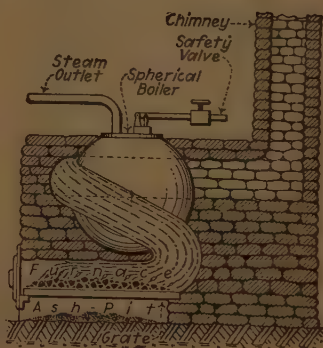


Fig. 8.—Desagalier's spherical boiler (year 1718).

This marked an advance in furnace construction, inasmuch as there was not, insofar as is known, any attempt made in

the design of the earlier boilers to guide the hot gases through paths where they would be most effective in evaporating the water.

16. Newcomen's Mushroom-Shaped Boiler Was The First Real Steam Generator (Figs. 9, 10 and 11).—It was built in 1705 and was used to generate steam for Newcomen's atmos-

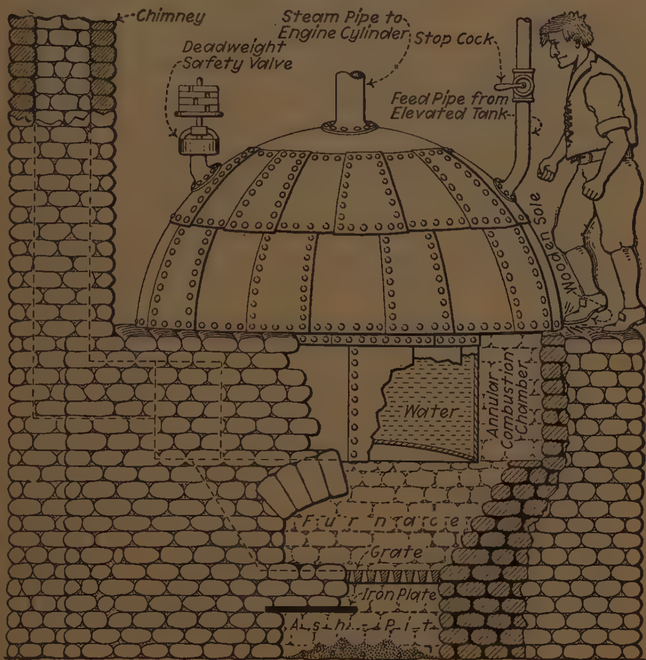


FIG. 9.—Newcomen's mushroom-shaped boiler.

pheric engine. Previous inventors had inclined generally to the spherical form of vessel as affording maximum strength. But as the engine developed by Newcomen was operated with steam at a very low pressure, he was able to depart somewhat from the spherical form. Hence, he designed a boiler that would give a greater proportional area of heating surface and so insure better economy.

17. The constructional details of Newcomen's boiler as illustrated in the contemporaneous prints, are reproduced in Figs. 9, 10 and 11. The upper half was hemispherical. The

lower half was cylindrical with a concave furnace- or crown-sheet. The spherical dome overhung the cylindrical shell beneath. It thus provided a means of suspension in the setting which permitted the arrangement of an annular combustion chamber around the shell. This boiler was, presumably, braced with some sort of diagonal or gusset stays which secured the flat ring- or base-sheet to the dome.

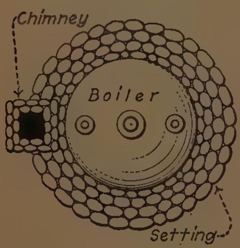


FIG. 10.—Top view of Newcomen's mushroom-shaped boiler.

18. The accessories of these primitive boilers included usually a dead-weight safety-valve. But they were often without gages for indicating the water level and steam pressure. The height of the water in the boiler was determined by the sound, hollow or otherwise, as given out by the boiler sheets when struck with a club, or kicked with the wooden-soled brogans worn by the attendant. The simmering of the safety valve indicated when the fire was sufficiently hot. The steam outlet was in the crown of the dome. The water was fed in from an elevated tank by gravity. A round manhole, which had its cover fastened on the outside with stud bolts, was provided in the dome.

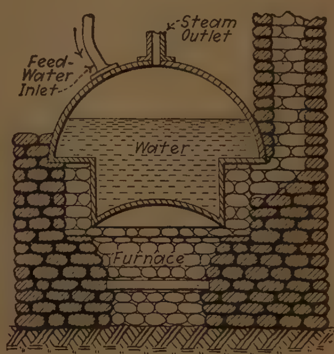


FIG. 11.—Section of Newcomen's boiler and setting (year 1705).

19. The Haystack Boiler Came Into Use About The Middle Of The Eighteenth Century (Fig. 12 and 13).—This was, probably, introduced by Smeaton and was a modification of the mushroom boiler. It was designed to provide greater strength. This was effected by eliminating the flat ring sheet, which formed the base of the dome, and by approaching throughout more nearly the spherical form. Its setting was similar to that of the mushroom boiler. An exception was that the furnace wall was drawn in near the bottom, to permit the

flange of the crown sheet to sustain the entire weight. Access from the furnace to the annular combustion chamber was provided by three or four openings (*O*, Fig. 12) in the masonry.

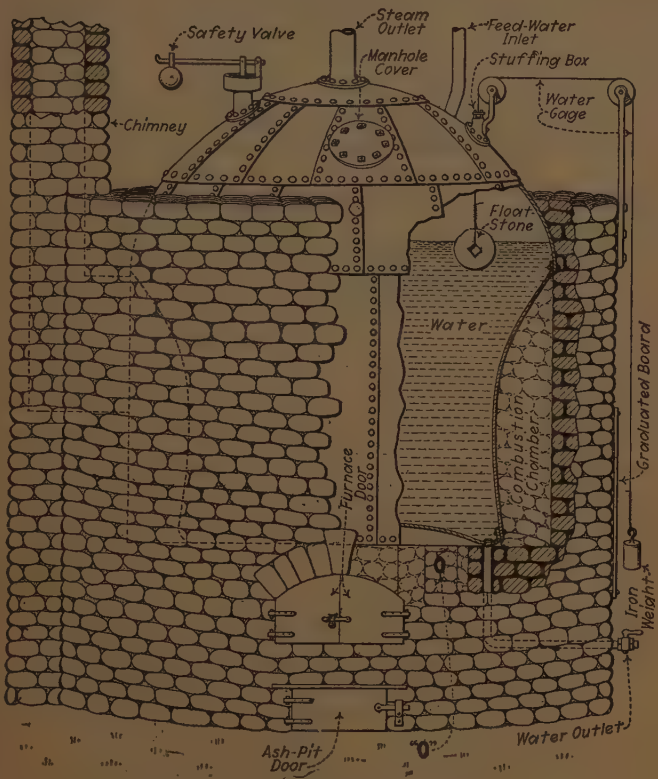


FIG. 12.—Haystack boiler.

NOTE.—These "haystack" boilers, so it is believed, were sometimes braced by tying the dome-sheet to the furnace sheet with through tension-rod stays. But they were generally constructed without stays. Many boilers of this type continued in use in England during the first quarter of the last century.

20. The equipment of the Haystack boiler (Fig. 12) shows improvements over that of its predecessor (Fig. 9). The accessories include a ball-and-lever safety valve and a "float-stone" for showing the water level. A "float-stone" con-

sisted usually of a worn-out grindstone hanging on a copper wire on the inside of the boiler. The wire passed out through a stuffing-box and ran over two pulleys to an iron weight. The stone rose and fell with the water level. The stage of water was indicated by the position of the weight in relation to graduations on a board in front of which the weight traveled up and down. A water-outlet pipe, with a stop-cock, was also provided.

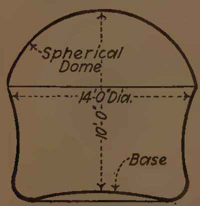


Fig. 13.—Diagrammatic sectional elevation of haystack boiler.

21. Watt's Wagon Boiler Was The First Radical Departure From The Spherical Form.—This boiler (Fig. 14) was designed by James Watt in about 1765. The upper half of this boiler was semi-cylindrical. The lower half was box-shape with concave sides. The bottom was concave and the ends were flat. The masonry was closed in at the upper and lower edges of the concave side sheets, so as to form flues along the sides. The two side flues were joined at the front end by a duct which was hollowed out in the masonry. They were separated at the back by a baffle-wall that divided the chimney from the

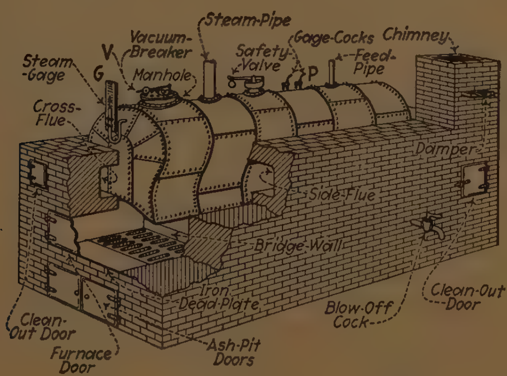


Fig. 14.—Watt's wagon-top boiler.

back connection. The products of combustion thus swept along the bottom sheet to the back end (about as shown in Fig. 15 for the egg-end boiler) returned through a side flue to the

front end, crossed to the opposite side flue and passed thence to the chimney.

NOTE.—It is probable that these "Wagon" boilers were sometimes braced by tying the side sheets together with stay-rods. But they were, generally, without braces of any kind. None of them could handle safely a pressure in excess of about 10 lb. per sq. in.

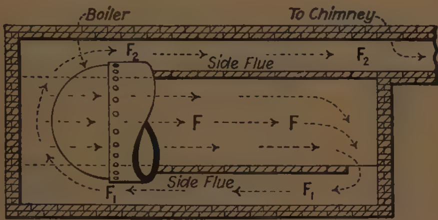


FIG. 15.—Wheel-draft circuit of the egg-end boiler.

22. The accessories of Watt's boilers included some appliances which were absent in the designs devised by his predecessors or which were used by them in cruder forms. Notable among Watt's fittings are the steam gauge, the water gage cocks and pipes and the vacuum-breaker. The steam gage, *G*, was merely a brass U-tube screwed into the front end of the boiler shell. It contained a quantity of mercury. A wooden float, which was carried on the surface of, and rose and fell with the mercury column in the outer leg of the U-tube, supported a slender arrow. Thereby, the pressure was indicated on a graduated scale which was attached to the tube. The water-gage pipes, *P*, extended down into the boiler. One of them treminated in the steam space an inch or two above the proper water level. The lower end of the other extended into the water space to a depth of about 2 in. below the normal water level. The vacuum-breaker, *V*, was a valve which opened inwards. It was designed to prevent collapse of the structure, by the external pressure of the atmosphere when, after being in service, the boiler was permitted to cool down.

23. The Egg-End Or Cylindrical Boiler (Fig. 16) Was The Next Development.—With the extended use of steam power during the closing years of the eighteenth century, there came a corresponding increase in the pressure required for the newer applications. Coincidently there developed a demand

for stronger steam-generating apparatus. About this time, the oddly shaped shell of the wagon-top boiler lost its vogue and was superseded by a shell of cylindrical form. Furthermore, the flat wrought-iron head-plates of the wagon boiler were displaced by thick hemispherical cast-iron heads,

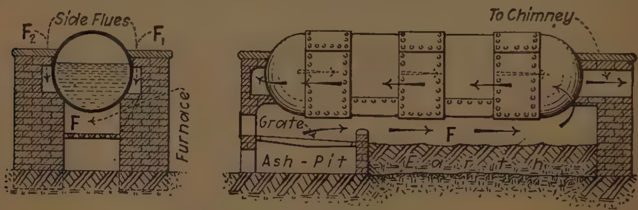


FIG. 16.—The egg-end or cylinder boiler (year 1790).

which tended to provide a boiler of somewhat oval or egg form (Fig. 15). However, in its settings and accessories, the egg-end boiler retained all of the essential characteristics of its immediate predecessor—the wagon-top. These inherited features included the arrangement of the side and cross flue (Fig. 15) for creating a "wheel draft," as the circuit of the furnace gases around the boiler was termed.

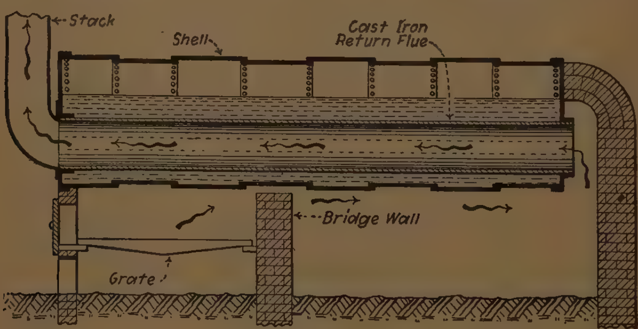


FIG. 17.—Longitudinal section of Evan's return-flue boiler (year 1800).

24. The idea of putting the return flue inside of the shell of the boiler instead of running it around outside was first conceived by an American Engineer, Oliver Evans, so it is believed. His invention (Fig. 17) was the direct forerunner of all subsequent designs of horizontal return-tubular and flue boilers. Some of these boilers made in about the year 1800 had cast-iron

shells and wrought-iron flues. The diameter of the flue was usually about half the shell diameter.

25. The Cornish boiler (Fig. 18) designed by Richard Trevithick, an English engineer connected with the Cornish mining industry, was the result of a plan to improve boiler economy. Trevithick proposed to locate the furnace inside of the flue. The original Cornish boiler, thus invented by

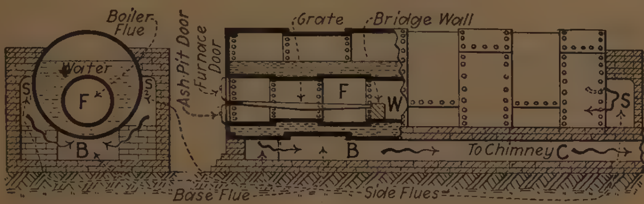


FIG. 18.—Transverse and longitudinal sections of the Cornish boiler (year 1802).

Trevithick, may be regarded as the forerunner of all internally-fired boilers of subsequent types. The boiler was built with a single flue sufficiently large to hold a furnace having a grate area proportioned properly to the available heating surface. The furnace was made by mounting the grate bars on bearing bars, which were secured crosswise to the flue, at the front and rear

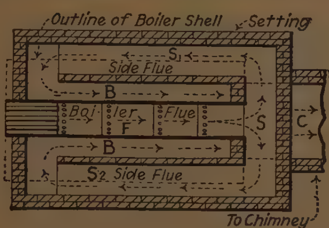


FIG. 19.—The Cornish boiler split-draft circuit.

ends of the furnace. A bridge wall, W, to hold the fire on the grate and to form an ash-pit, was erected at the rear of the furnace.

NOTE.—THE CURRENT OF THE FURNACE GASES (Fig. 19) passing out of the flue at the rear end, S, divided and returned through side flues, S_1 and S_2, to the front end. From thence they flowed through a single flue, B, along the bottom of the shell and into the smoke conduit, C, at the rear.

26. The first water-tube boiler which embodied the fundamental structural details of modern boilers of this class was the invention of James Barlow about the year 1793. This boiler (Fig. 20) had front and rear water legs. It consisted of a cubical wrought-iron box having within it a smaller box-like structure. A number of straight tubes extended across from side to side within the smaller box. The preponderance of unstayed flat surface, the exposed top sheet of the fire box, and the restricted water circulation, were all obvious disadvantages of this design. It was, perhaps, safe for the pressure commonly employed in its time—3 to 7 lb. per sq. in.

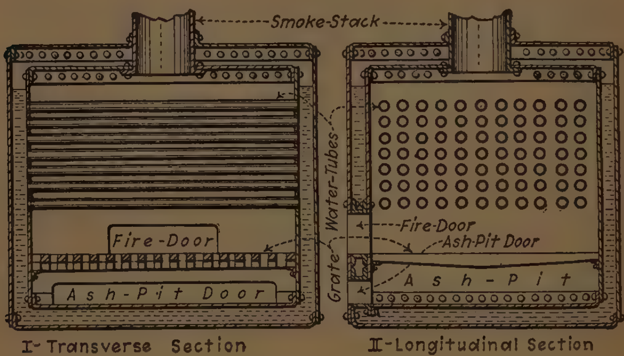


FIG. 20.—Longitudinal and transverse sections of Barlow's horizontal water-tube boiler (year 1793).

27. A Boiler Of The Porcupine Type Was Devised By James Cox Stevens (Fig. 21) in 1804.—In it a number of blind or pocket tubes were secured in the inclined front and rear faces of a cast-iron water chamber *W* having a rectangular crosssection. The products of combustion in passing to the chimney *S* circulated among the tubes *B*. The water chamber served as a baffle wall, to deflect downward the current of gases through the front bank of tubes and up through the rear bank. A tall steeple-shaped steam dome *D*, made of wrought-iron plates and strengthened with wrought-iron bands shrunk on outside, was bolted to the top of the water chamber.

NOTE.—The Stevens Porcupine boiler was built for a working pressure of 50 lb. per sq. in. It marked a definite advance in the design

of high-pressure steam-generating apparatus. Its most serious defect appears to have been the impossibility of adequate water-circulation in the tubes. This resulted in the tube ends filling with sediment and burning off

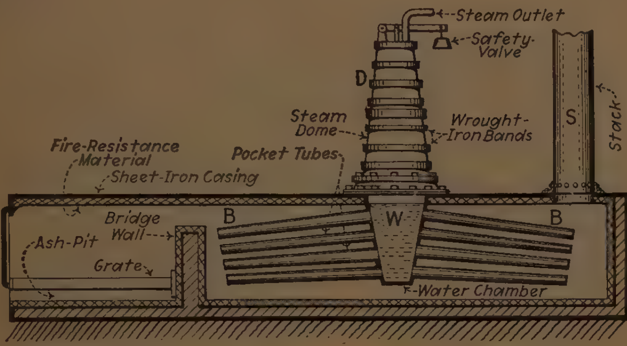


FIG. 21.—Illustration of Steven's porcupine boiler (year 1804).

28. Wilcox's water-tube boiler (Fig. 22) was invented in 1856. This boiler incorporated the general feature of Barlow's (Fig 20) early attempt. But it was vastly superior both in design and operation. The water leg extended entirely around

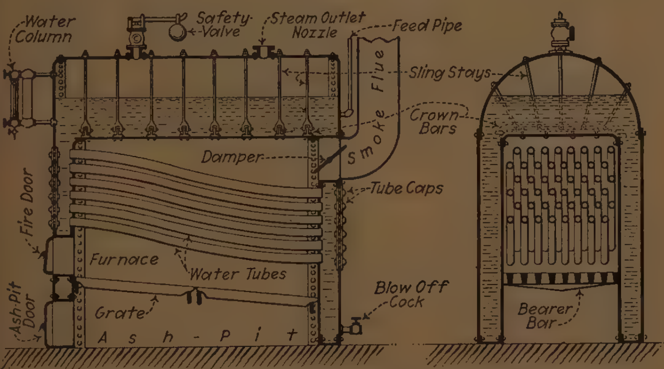


FIG. 22.—Wilcox's boiler with inclined water tubes (year 1856).

the fire box. A nest of water tubes, which had a downward inclination, traversed the fire box from front to rear. The crown sheet of the fire box was braced with sling stays which were secured to the semi-cylindrical top sheet. The inner

and outer sheets of the water leg were tied together with stay bolts. From this elementary design were evolved the various classes of modern water-tube boilers which have inclined tubes that connect front and rear headers or legs.

29. The First Sectional Boiler Having Inclined Water Tubes Was Made By George Twibill (Fig. 23) in 1865.—A nest of inclined wrought-iron tubes traversed the combustion chamber from side to side. The separate fore-and-aft rows of tubes connected, at each side, to horizontal manifolds or headers. These headers were attached, front and rear, to standpipes which carried the steam to two superimposed drums above.

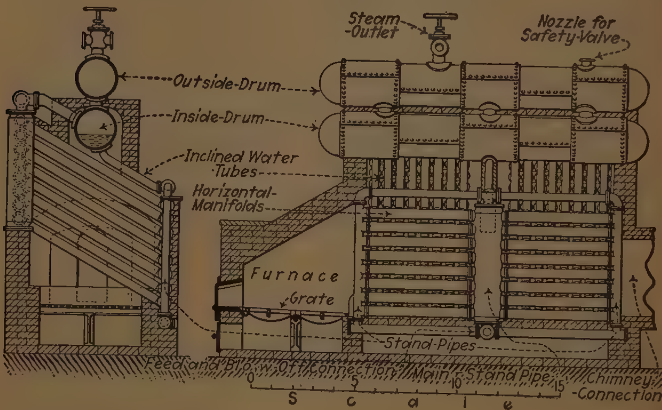


FIG. 23.—Twibill's sectional water-tube boiler (year 1865).

One drum was inside, the other outside, the masonry. The water of entrainment was collected in the lower drum and passed thence to the lower set of manifolds.

30. The Babcock & Wilcox sectional water-tube boiler of early form, as shown in Fig. 24, was built about 1870. In it were represented the essential constructional principles which were developed and refined in the later designs. The tubes were of wrought iron. The vertical header sections were of cast iron. The two were joined together, in the foundry, by laying the tubes in the mold and casting on the headers. A vertical baffle, erected midway, caused the gases of com-

bustion to make two passes through the nest of tubes. The external wall of the setting was built to form a connection to the chimney.

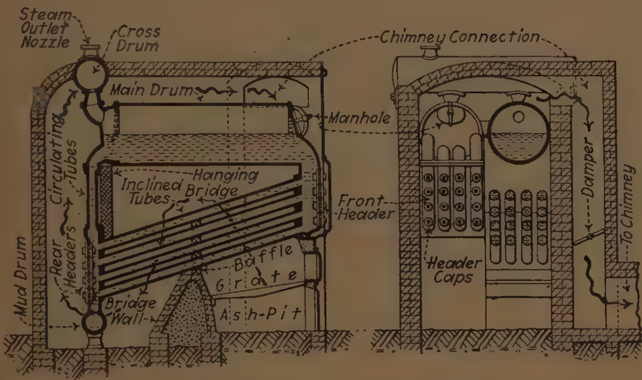


FIG. 24.—Early form of Babcock & Wilcox boiler (year 1870).

QUESTIONS ON DIVISION 2

1. At what period did boilers of practical use, as viewed from a modern standpoint, begin to appear?

2. (a) What nations of antiquity built the first boilers? (b) What were the uses of boilers in ancient times? (c) In what antique construction was the water-tube principle irst revealed?

3. Describe the first recorded use of steam for developing mechanical work.

4. Was the "steam bombshell" a boiler or an infernal machine?

5. Describe the first recorded use of steam for producing mechanical motion by eaction.

6. To whom is ascribed the invention of the lever safety valve?

7. To whom is ascribed the first definite adaptation of the furnace and setting to the oiler structure?

8. What was the form of Savary's 1702 boiler?

9. Whose was the first recorded attempt at realizing the full steam-making effective-ess of a boiler?

10. (a) To what structural shape did primitive steam-boilers generally conform? b) Why were they so shaped? (c) What was Newcomen's purpose in departing from onventional practice in this regard? (d) What circumstance favored him in the adopon of a less stable shape?

11. Describe the structural details of Newcomen's boiler.

12. (a) What was a common expedient for finding the water level in the mushroom-opped boiler? (b) How was the water replenished? (c) How did the attendant know hen the fire was hot enough?

13. (a) Describe the structural details of the haystack boiler. (b) In what respect as the "haystack" form of construction an improvement on the preceding type?

14. Describe a "float-stone" water-gage.

15. (a) Describe the wagon boiler. (b) What advantage, over the preceding type, was ne wagon boiler designed to secure? (c) What was the maximum safe pressure for a agon boiler?

16. (*a*) Name the principal appliances used on Watt's boilers. (*b*) Describe the steam gage. (*c*) The vacuum breaker. (*d*) The water gages.

17. (*a*) At what period did the egg-end boiler come into use? (*b*) What were the circumstances of its adoption as the prevailing type? (*c*) In what respect was the egg-end boiler an improvement on the wagon boiler? (*d*) Explain the meaning of "wheel-draft?"

18. (*a*) To whom is ascribed the invention of the return-flue boiler? (*b*) What materials were used in the early boilers of this type? (*c*) What was the usual ratio of shell-diameter to flue-diameter?

19. (*a*) Where and by whom was the Cornish boiler first used? (*b*) What incentive led to the design of this boiler? (*c*) How were the gas passes arranged?.

20. (*a*) Describe Barlow's water-tube boiler. (*b*) What were the outstanding disadvantages of this boiler?

21. (*a*) Describe Steven's porcupine boiler. (*b*) What was the principal objection to this design?

22. What outstanding feature of Wilcox's 1856 boiler distinguishes it as the prototype of modern horizontal water-tube boilers?

23. Describe the general arrangement of the principal elements of the first sectional boiler with inclined water-tubes.

24. How were the tubes joined with the headers in the early forms of Babcock & Wilcox boilers?

DIVISION 3

MODERN TYPES OF BOILERS

31. The plain-cylindrical boiler is the sole survivor of the primitive types which are described in the preceding Div. The plain-cylindrical boiler (Fig. 25) is, obviously, of the externally-fired class. Figs. 26, 27, 28, and 29 show details. The heads of these boilers are, usually, of hemispherical form. This shape gives the structure an inherent strength which renders unnecessary the use of braces. Cast-iron heads were formerly often employed. The castings were an

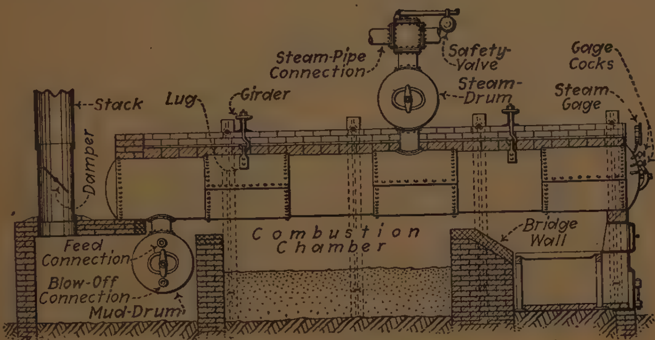


FIG. 25.—Sectional view of setting of plain cylinder boiler.

inch or more in thickness. Wrought iron or steel plate is now used instead. The thickness of the shell metal is rarely more than ¼ in.

NOTE.—Plain cylindrical boilers in certain of the old installations were 36 in. in diameter and 90 ft. long. But the usual diameter is from 30 to 42 in., and the length from 20 to 50 ft.

32. A battery, or nest, of plain-cylindrical boilers (Fig. 29) consists of a group of from two to four shells enclosed side by side in the setting and arranged over a common furnace.

With such installations, a transverse mud drum at the rear (Fig. 25) and a steam drum at the front (Fig. 29) are joined to the individual boilers by short necks.

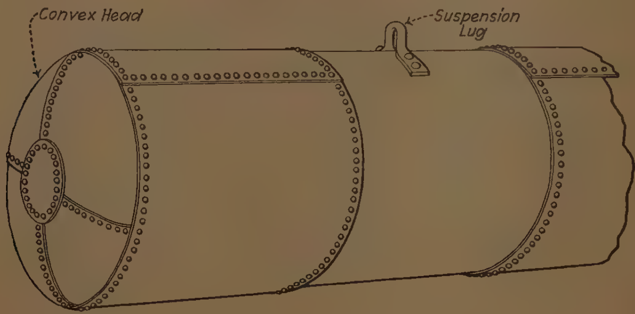


FIG. 26.—Plain cylindrical boiler.

33. The double-cylindrical boiler (Fig. 30) was designed in an effort to realize good economy without departing radically from the simplicity which distinguishes the plain-cylinder boiler.

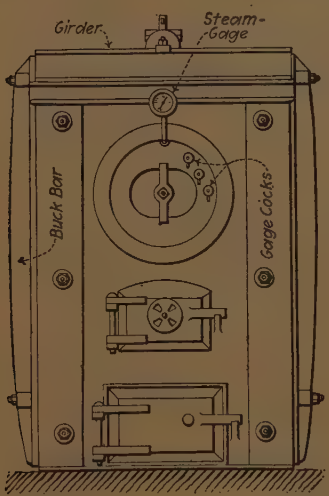


FIG. 27.—Front elevation of plain-cylindrical boiler. (A gage glass in addition to gage cocks are supplied on modern cylindrical boilers.)

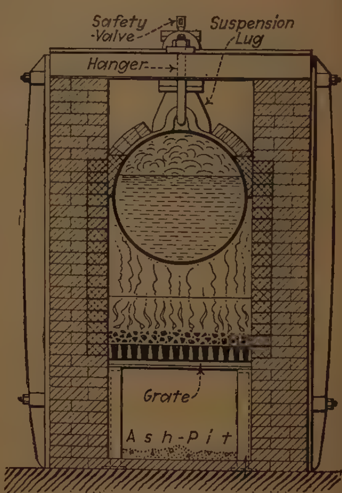


FIG. 28.—Cross-sectional elevation of plain-cylindrical boilers.

34. Fire-Tube Boilers Are Either Externally Fired Or Internally Fired (Sec. 4).—Externally-fired boilers have a separate furnace built outside of the shell of the boiler. In the internally-fired boilers, the furnace forms an integral part within the boiler structure.

NOTE.—THE DISTINCTION BETWEEN A "FLUE" AND A "TUBE" in the nomenclature of boiler design, is one of degree rather than kind. Flue tubes less than 6 in. in diameter have been arbitrarily styled "tubes."

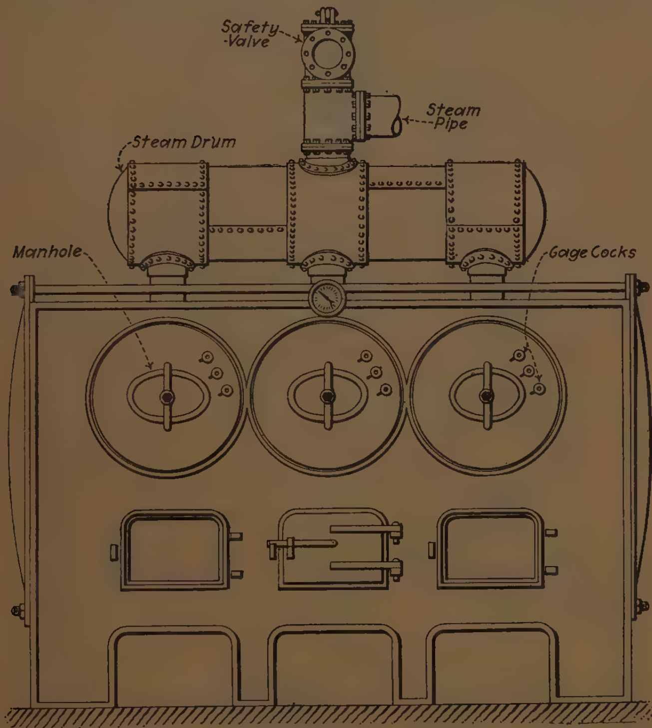


FIG. 29.—Front elevation of battery of plain-cylinder boilers (two fire doors and three ash-pit doors are omitted from the illustration).

Those of larger diameters have likewise, if used as gas passages, been called "flues."

NOTE.—The double cylindrical boiler may be suspended (Fig. 30) from the ends of equalizing levers. These are balanced at their middle points on pivot bars, the ends of which rest on iron columns which are built into the side walls of the setting. The attachment of the suspension rods to the shell of the upper cylinder is of essentially the same form as

that used for the plain-cylindrical boiler (Fig. 28). The levers insure a uniform distribution of the load among the four suspension eyes on the shell.

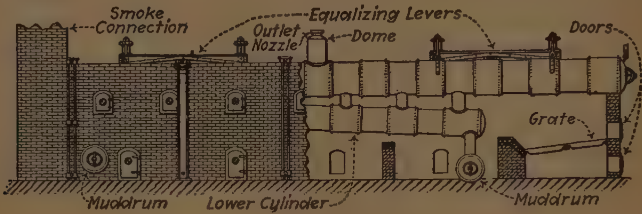


Fig. 30.—Double cylindrical boiler.

35. The Elephant Boiler (Fig 31) is a modified form of the double cylindrical boiler. As built in France, this type has two cylinders (Fig. 32) suspended from the upper main shell.

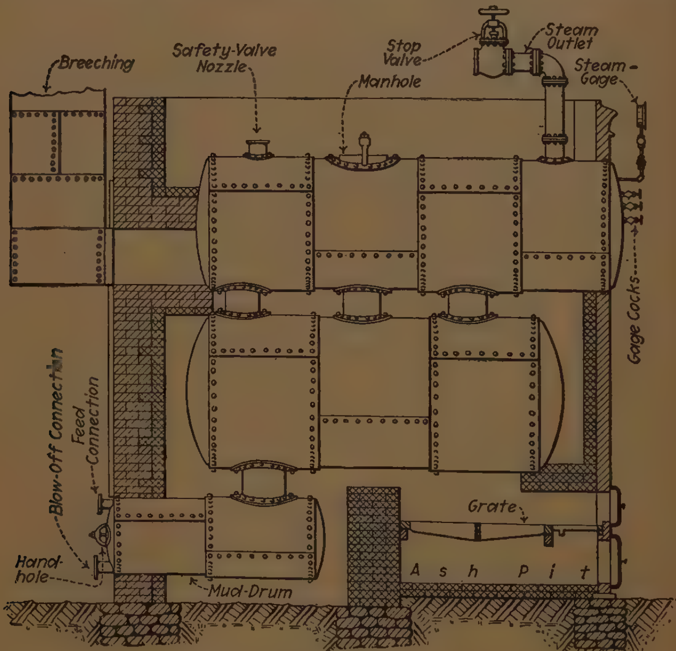


Fig. 31.—Elephant boiler.

36. The return-flue boiler with two or more flue tubes (Figs. 33, 34, and 35) ranging in diameter from 6 to 18 in., is the simplest modern example of fire-tube boilers of the

externally-fired class. In boilers of this design, the hot flue gases pass along toward the back under the shell and return through the flues to the front end and pass thence to the

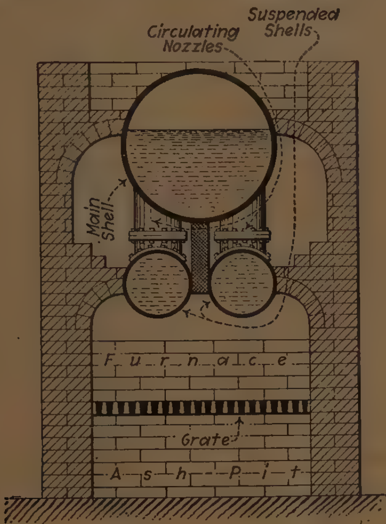


Fig. 32.—Cross-sectional elevation of French standard boiler.

stack. This returning of the gases of combustion through the flues provides a better proportion of heating surface to the

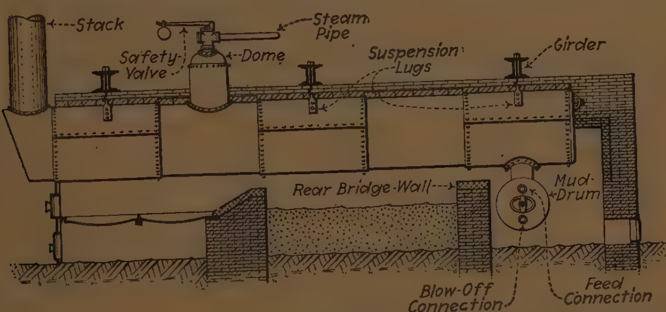


Fig. 33.—Sectional view of return-flue boiler. (In the older flue boiler settings the space between the two bridge walls was usually filled with ashes as shown. But in modern practice this filling is omitted with a resulting increase in combustion economy.)

volume of contained water. Thus the boiler has an advantage as to economy over those of the plain-cylinder type.

Note.—The Methods Of Supporting The Flue Boiler are identical with those used for the plain-cylinder type. Also, in other prominent external features the two constructions are similar. The main difference is that the chimney connection is at the front end of the flue boiler instead of at the rear end.

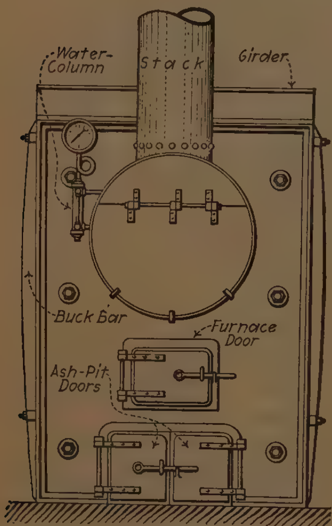


Fig. 34.—Front elevation of return-flue boiler

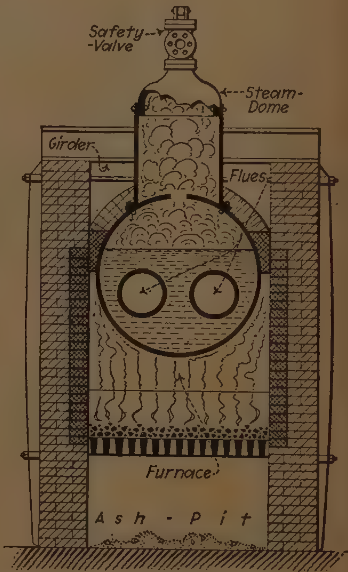


Fig. 35.—Cross-sectional view of return-flue boiler and setting.

37. The horizontal return tubular or multi-tubular boiler (Fig. 36) is a development of the return-flue boiler. It was evolved by replacing a few large-diameter flue-tubes with many of comparatively small diameter. Because of this, these boilers are called "multi-tubular." It is similar to the return-flue variety of fire-tube boilers in all general characteristics of design. The main point of difference is that the proportionate extent of heating surface is greatly increased. Thereby the economy of the boiler is correspondingly improved.

Side and front views of a typical boiler of this class are presented in Figs. 36, 37, and 38. Modern furnaces and settings for return-tubular boilers are shown in Figs. 348 and 349.

NOTE.—The horizontal-return tubular boiler has for years been regarded as the standard American type. In general, these boilers can not, profitably be driven to more than 150 per cent. of their rated capacities.

38. As To Return-Tubular Boiler Number Of Tubes, Proportions And Thicknesses (See Table 42) there are from about 24 3-in. tubes, in a 36-in. shell, to 88 4-in. or 110 3½-in. tubes, in a 78-in. shell. Shells vary in thickness, as determined by the diameter, from ¼ to ½ in. Thickness of heads varies from ⅜ in., for boilers with 36-in shells, to 9/16 in. for those with 78-in. shells. The lengths range from 8 to 20 ft.

39. The steam space in a return tubular boiler is restricted

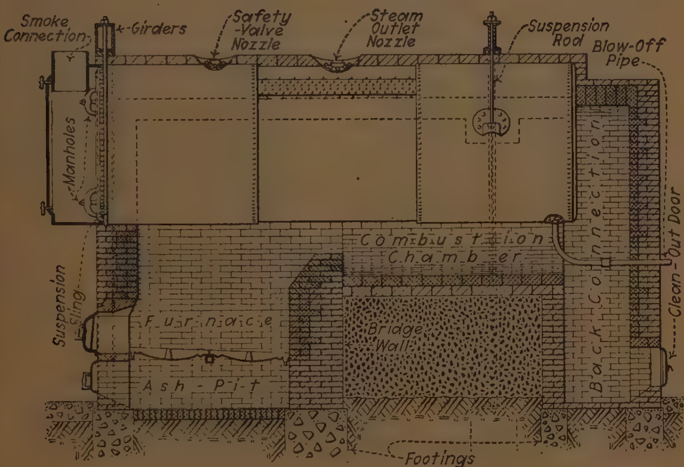


FIG. 36.—General features of horizontal return-tubular boiler. (As explained in Div. 16, it is modern practice to provide a combustion chamber much larger than that illustrated above.)

to about one-third of the total volume of the shell. The remaining two-thirds, less the volume occupied by the tubes, is water space. Hence, the pressure tends to fluctuate less in this boiler than in the previously described modern types which have relatively less water space.

40. Two Methods Of Supporting Return-Tubular Boilers Are In Common Use.—One method is (Fig. 38) by suspension from rods secured above to channel-beams which bear on steel columns. The rods engage with lugs riveted to the shell

(Figs. 36 and 38). The other method (Fig. 39) employs brackets which are riveted to the shell. The brackets rest

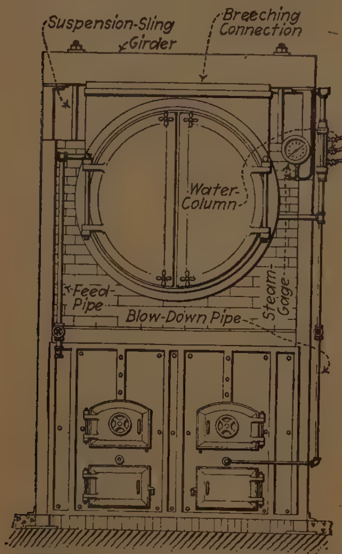


FIG. 37.—Front elevation of horizontal return-tubular boiler.

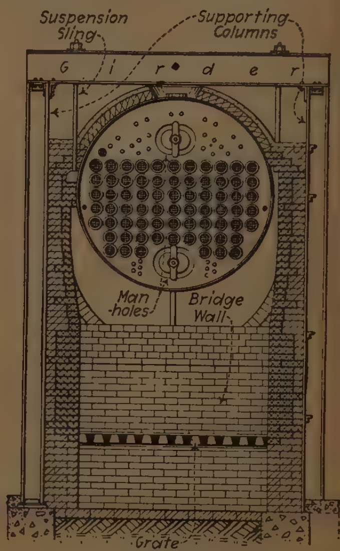


FIG. 38.—Cross-sectional elevation through furnace of horizontal return-tubular boiler.

on iron plates set in the brickwork. With the former method, the expansive action of the boiler shell is unhampered by the

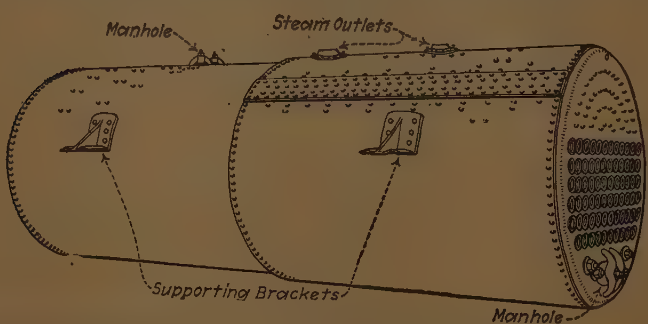


FIG. 39.—Horizontal return-tubular boiler with supporting brackets.

restraint which the masonry imposes in the latter case. See also Figs. 348 and 349 for illustrations of suspension methods.

41. Standard dimensions and specifications for return-tubular boilers are reproduced in Table 42 and Fig. 40 and also in the following paragraphs. Excerpts from specifications

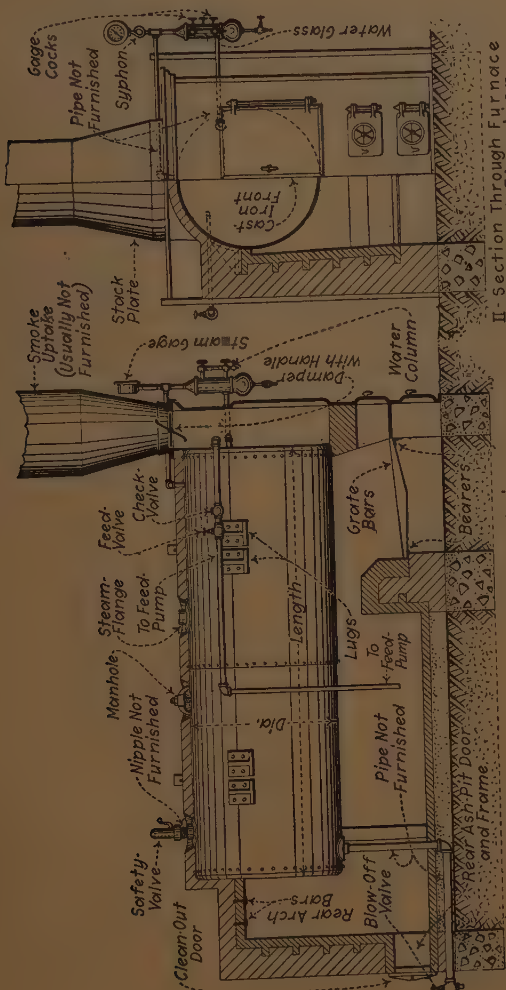


FIG. 40.—Illustrating standard equipment for return-tubular boilers. (Freeman & Sons.)

used by the National Association of Tubular Boiler Manufacturers are given below. These or similar specifications have been adopted generally by return-tubular boiler manufacturers

42. Table—Specifications For Standard Return Tubular Boilers

(S. Freeman & Sons Manufacturing Company, Racine, Wisconsin)

A Standard Return-tubular Boiler Equipment Includes: The bare boiler with lugs or hangers. Cast-iron front, full or half as preferred, with anchors. Grate-bars with bearers. Rear arch-bars. Rear ash-pit door and frame. Safety valve. Steam-gage with siphon. Water-column, with gage-glass and three gage-cocks. Blow-off valve. Check-valve. Stop-valve for water feed-line. Stack-plate or nozzle, either equipped with damper, with each full-front boiler. Where customer so specifies a steel smoke-stack and guys are furnished; stacks less than 60 ft. long have four guy eyes and a steel guy cable six times as long as the stack. Stacks of 60 ft. or greater length have six guy eyes, two sets of three each, and a guy line ten times as long as the stack.

100 Lb. Per Sq. In. Working Pressure (Longitudinal Seams all Butt Jointed, Double-Riveted																			
Horse-power of boiler as rated	15	20	25	30	35	40	45	50	60	70	80	90	100	110	125	150	165	180	200
Diameter of boiler......in.	36	36	36	44	44	44	48	48	54	54	60	60	66	66	72	72	72	78	78
Length of tubes........ft.	8	10	12	10	12	14	12	14	14	16	16	18	16	18	16	18	20	18	20
Number of 3-inch tubes...	24	24	24	36	36	36	46	46	....	....	....	....	....	....	....	....	....	....	....
Number of 3½-inch tubes.	....	....	....	28	28	28	34	34	44	44	54	54	66	66	88	86	86	110	110
Number of 4-inch tubes...	....	....	....	....	....	....	28	28	36	36	44	44	54	54	70	70	70	88	88
3-inch tubes, heating surface...........sq. ft.	150.8	188.5	226.2	282.7	339.2	395.8	433.5	505.8	....	....	....	....	....	....	....	....	....	....	....
3½-inch tubes, heating surface............sq. ft.	....	....	....	256.6	307.9	359.2	373.9	436.2	564.4	645.1	791.7	890.6	967.6	1088.6	1260.8	1418.4	1576.0	1814.0	2015.9
4-inch tubes, heating surface...........sq. ft.	....	....	....	....	....	....	351.9	410.5	527.8	603.2	737.2	829.4	904.8	1017.9	1172.9	1319.5	1466.0	1658.8	1843.1
Shell heating surface, sq. ft.	50.3	62.8	75.4	76.8	92.2	107.5	100.5	117.3	131.9	150.8	167.6	188.5	184.3	207.4	201.1	226.2	251.3	245.2	272.4
Thickness of shell......in.	1/4	1/4	1/4	5/16	5/16	5/16	5/16	5/16	5/16	5/16	11/32	11/32	3/8	3/8	7/16	7/16	7/16	1/2	1/2
Thickness of heads.....in.	3/8	3/8	3/8	7/16	7/16	7/16	7/16	7/16	7/16	7/16	1/2	1/2	1/2	1/2	1/2	1/2	1/2	9/16	9/16
Width of grates........in.	36	36	36	42	42	42	48	48	54	54	60	60	66	66	72	72	72	78	78
Length of grates.......in.	36	36	42	36	42	48	42	48	48	54	54	60	54	60	54	60	66	60	66
Area of grates......sq. ft.	9.0	9.0	10.5	10.5	12.25	14.0	14.0	16.0	18.0	20.25	22.5	25.0	24.75	27.5	27.0	30.0	33.0	32.5	35.75
Diameter of stack......in.	16	16	16	22	22	22	24	24	26	26	26	26	30	30	34	34	34	38	38
Length of stack........ft	30	35	40	35	40	50	40	50	50	60	60	60	60	60	60	60	70	60	70
Gauge of stack..........	16	16	16	16	16	16	16	16	16	16	14	14	14	14	14	14	14	12	12
Length of guys........ft.	180	210	240	210	240	300	240	300	300	600	600	600	600	600	600	600	700	600	700
Diameter of guys .....in.	3/16	3/16	3/16	1/4	1/4	1/4	1/4	1/4	1/4	1/4	5/16	5/16	5/16	5/16	5/16	5/16	5/16	3/8	3/8

APPROXIMATE WEIGHTS

Bare boiler, for full front	2300	2700	3100	3600	4100	4600	5300	5900	7500	8300	10100	11200	12300	13600	15400	17000	18500	21500	23250
Bare boiler, for half front*	2500	2900	3300	3900	4400	4900	5700	6300	8000	8800	10800	11900	13100	14400	16400	18000	19500	22500	24300
Full front and other castings	1925	1925	1975	2450	2550	2650	3040	3140	3430	3530	3870	4020	4830	4980	5180	5280	5430	6400	6900
Half front and other castings	1325	1325	1375	1800	1900	2000	2040	2140	2430	2530	2670	2820	3480	3630	3680	3780	3930	4550	5050
Trimmings	80	80	80	100	100	100	130	130	130	130	140	140	150	150	180	180	180	190	190
Stack and guys	360	420	480	595	680	850	720	900	1000	1200	1620	1620	1740	1740	1980	1980	2310	2600	3000
Weight complete, full front	4665	5125	5635	6745	7430	8200	9190	10070	12060	13160	15730	16980	19020	20470	23040	24740	26720	30450	33150
Weight complete, half front	4265	4725	5235	6395	7080	7850	8590	9470	11560	12660	15230	16480	18470	19920	22240	23940	25920	29650	32350
Fire door arches, full front	200	200	200	200	200	200	400	400	400	400	500	500	500	500	600	600	600	600	600
Fire door arches, half front	100	100	100	100	100	100	200	200	200	200	200	200	300	300	300	300	300	300	300

125 Lb. Per Sq. In. Working Pressure (Longitudinal seams all Butt Jointed, Triple-Riveted)

Diameter of boiler, in.	....	....	....	....	....	....	48	48	54	54	60	60	66	66	72	72	72	78	78
Length of tubes, ft.	....	....	....	....	....	....	12	14	14	16	16	18	16	18	16	18	20	18	20
Number of 3-inch tubes	....	....	....	....	....	....	46	46	....	....	....	....	....	....	....	....	....	....	....
Number of 3½-inch tubes	....	....	....	....	....	....	34	34	44	44	54	54	66	66	86	86	86	110	110
Number of 4-inch tubes	....	....	....	....	....	....	28	28	36	36	44	44	54	54	70	70	70	88	88
3-inch tubes, heating surface, sq. ft.	....	....	....	....	....	....	433.5	505.8	....	....	....	....	....	....	....	....	....	....	....
3½-inch tubes, heating surface, sq. ft.	....	....	....	....	....	....	373.9	436.2	364.4	645.1	791.7	890.6	967.6	1088.6	1260.8	1418.4	1576.0	1814.0	2015.9
4-inch tubes, heating surface, sq. ft.	....	....	....	....	....	....	351.9	410.5	527.8	603.2	737.2	829.4	904.8	1017.9	1172.9	1319.5	1466.0	1658.8	1843.1
Shell heating surface, sq. ft.	....	....	....	....	....	....	100.5	117.3	131.9	150.8	167.6	188.5	184.3	207.4	201.1	226.2	251.3	245.2	272.4
Thickness of shell, in.	....	....	....	....	....	....	11/32	11/32	3/8	3/8	13/32	13/32	7/16	7/16	1/2	1/2	1/2	17/32	17/32
Thickness of heads, in.	....	....	....	....	....	....	7/16	7/16	7/16	7/16	1/2	1/2	1/2	1/2	1/2	1/2	1/2	9/16	9/16
Width of grates, in.	....	....	....	....	....	....	48	48	54	54	60	60	66	66	72	72	72	78	78
Length of grates, in.	....	....	....	....	....	....	42	48	48	54	54	60	54	60	54	60	66	60	66
Area of grates, sq. ft.	....	....	....	....	....	....	14.0	16.0	18.0	20.25	22.5	25.0	24.75	27.5	27.0	30.0	33.0	32.5	35.75
Diameter of stack, in.	....	....	....	....	....	....	24	24	26	26	28	28	30	30	34	34	34	38	38
Length of stack, ft.	....	....	....	....	....	....	40	50	50	60	60	60	60	60	60	60	70	60	70
Gauge of stack	....	....	....	....	....	....	16	16	16	16	14	14	14	14	14	14	14	12	12
Length of guys, ft.	....	....	....	....	....	....	240	300	300	600	600	600	600	600	600	600	700	600	700
Diameter of guys, in.	....	....	....	....	....	....	1/4	1/4	1/4	1/4	5/16	5/16	5/16	5/16	5/16	5/16	5/16	3/8	3/8

APPROXIMATE WEIGHTS

Horse-power of boiler as rated	15	20	25	30	35	40	45	50	60	70	80	90	100	110	125	150	165	180	200
Bare boiler, for full front	....	....	....	....	....	....	6300	7000	8800	9800	12200	13500	14900	16400	18400	20000	21600	24000	26000
Bare boiler, for half front	....	....	....	....	....	....	6700	7400	9300	10300	12900	14200	15700	17200	19400	21000	22600	25300	27300
Full front and other castings	....	....	....	....	....	....	3040	3140	3430	3530	3870	4020	4830	4980	5180	5280	5430	5650	5860
Half front and other castings	....	....	....	....	....	....	2040	2140	2430	2530	2670	2820	3480	3630	3680	3780	3930	4260	4470
Trimmings	....	....	....	....	....	....	130	130	130	130	140	140	150	150	180	180	180	190	190
Stacks and guys	....	....	....	....	....	....	720	900	1000	1200	1620	1620	1740	1740	1980	1980	2310	2820	3290
Weight complete, full front	....	....	....	....	....	....	10190	11170	13360	14660	17830	19280	21620	23270	25740	27440	29520	32660	35340
Weight complete, half front	....	....	....	....	....	....	9190	10170	12360	13660	17330	18780	21070	22720	25240	26940	29020	32570	35250
Fire door arches, full front	....	....	....	....	....	....	400	400	400	400	500	500	500	500	600	600	600	600	600
Fire door arches, half front	....	....	....	....	....	....	200	200	200	200	200	200	300	300	300	300	300	300	300

150 Lb. Per Sq. In. Working Pressure (Longitudinal Seams all Butt-Jointed, Quadruple-Riveted)

Horse-power of boiler as rated	15	20	25	30	35	40	45	50	60	70	80	90	100	110	125	150	165	180	200
Diameter of Boiler, in.	....	....	....	....	....	....	48	48	54	54	60	60	66	66	72	72	72	78	78
Length of Tubes, ft.	....	....	....	....	....	....	12	14	14	16	16	18	16	18	16	18	20	18	20
Number of 3-inch Tubes	....	....	....	....	....	....	46	46	....	....	....	....	....	....	....	....	....	....	....
Number of $3\frac{1}{2}$-inch Tubes	....	....	....	....	....	....	34	34	44	44	54	54	66	66	86	86	86	110	110
Number of 4-inch Tubes	....	....	....	....	....	....	28	28	36	36	44	44	54	54	70	70	70	88	88
3-inch tubes, heating surface, sq. ft.	....	....	....	....	....	....	433.5	505.8	....	....	....	....	....	....	....	....	....	....	....
$3\frac{1}{2}$-inch tubes, heating surface, sq. ft.	....	....	....	....	....	....	373.9	436.2	564.4	645.1	791.7	890.6	967.6	1088.6	1260.8	1418.4	1576.0	1814.0	2015.9
4-inch tubes, heating surface, sq. ft.	....	....	....	....	....	....	351.9	410.5	527.8	603.2	737.2	829.4	904.8	1017.9	1172.9	1319.5	1466.0	1658.8	1843.1
Shell heating surface, sq. ft.	....	....	....	....	....	....	100.5	117.3	131.9	150.8	167.6	188.5	184.3	207.4	201.1	226.2	251.3	245.2	272.4
Thickness of shell, in.	....	....	....	....	....	....	3/8	3/8	13/32	13/32	7/16	7/16	1/2	1/2	17/32	17/32	17/32	19/32	19/32
Thickness of head, in.	....	....	....	....	....	....	7/16	7/16	7/16	7/16	1/2	1/2	1/2	1/2	9/16	9/16	9/16	9/16	9/16
Width of grates, in.	....	....	....	....	....	....	48	48	54	54	60	60	66	66	72	72	72	78	78
Length of grates, in.	....	....	....	....	....	....	42	48	48	54	54	60	54	60	54	60	66	60	66
Area of grates, sq. ft.	....	....	....	....	....	....	14.0	16.0	18.0	20.25	22.5	25.0	24.75	27.5	27.0	30.0	33.0	32.5	35.75
Diameter of stack, in.	....	....	....	....	....	....	24	24	26	26	28	28	30	30	34	34	34	38	38
Length of stack, ft.	....	....	....	....	....	....	40	50	50	60	60	60	60	60	60	60	70	60	70
Gauge of stack	....	....	....	....	....	....	16	16	16	16	14	14	14	14	14	14	14	12	12
Length of guys, ft.	....	....	....	....	....	....	240	300	300	600	600	600	600	600	600	600	700	600	700
Diameter of guys, in.	....	....	....	....	....	....	1/4	1/4	1/4	1/4	5/16	5/16	5/16	5/16	5/16	5/16	5/16	3/8	3/8

APPROXIMATE WEIGHTS

Bare boiler for full front							5900	6600	8300	9200	11200	12400	13600	15000	16800	18400	20000	23000	25000
Bare boiler for half front *							6300	7000	8800	9700	11900	13100	14400	15800	17800	19400	21000	24300	26300
Full front and other castings							2040	3140	3430	3530	3870	4020	4830	4980	5180	5280	5430	5650	5860
Half front and other castings							3040	2140	2430	2530	2670	2820	3480	3630	3680	3780	3930	4260	4470
Trimmings							130	130	130	130	140	140	150	150	180	180	180	190	190
Stack and guys							720	900	1000	1200	1620	1620	1740	1740	1980	1980	2310	2820	3290
Weight complete, full front							9790	10770	12860	14060	16830	18180	20320	21870	24440	26140	28220	31660	34340
Weight complete, half front							9190	10170	12360	13560	16330	17680	19770	21320	23640	25340	27420	30270	32950
Fire door arches, full front							400	400	400	400	500	500	500	500	600	600	600	600	600
Fire door arches, half front							200	200	200	200	200	200	300	300	300	300	300	300	300

SIZES OF TRIMMINGS FOR ALL BOILERS

Steam opening ....in.	2½	2½	2½	2½	3	3	3	3	3½	3½	4	5	5	5	5	6	6	6	6
Pop safety valve.......in.	1¼	1¼	1½	1½	1½	2	2	2	2½	2½	2½	3	3	3	4	4	4	4	4
Water gauge glass......in.	⅝	⅝	⅝	⅝	⅝	⅝	⅝	⅝	¾	¾	¾	¾	¾	¾	¾	¾	¾	¾	¾
Water column connections in.	¾	¾	¾	1	1	1	1	1	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼
Gauge cocks..........in.	¾	¾	¾	¾	¾	¾	¾	¾	¾	¾	¾	¾	¾	¾	¾	¾	¾	¾	¾
Blow-off..............in.	1½	1½	1½	1½	1½	1½	1½	1½	2	2	2	2	2	2	2	2½	2½	2½	2½
Feed and check valves..in.	1	1	1	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1½	1½	1½	1½	1½	1½	2	2
Steam-gauge dial......in.	5	5	5	5	5	5	5	5	8½	8½	8½	8½	8½	8½	8½	8½	8½	8½	8½

* Smoke Extension and doors included.

for boilers for installation in states where the A.S.M.E. Boiler Code is not effective. In general, the stipulations of these specifications are about the same as, but possibly less stringent than, those of the A.S.M.E. Code.

Materials.—The shell, heads, and covering strips of the standard boiler shall be of flange steel, as described in the standard specifications of the Association of American Steel Manufacturers. All such plates shall be marked 60,000 lb. tensile strength, and, in building the boiler, the plates shall be so placed that these stamps are plainly visible on the outside. These plates shall have the full specified thickness at the edges and shall meet the tensile, quenching and bending tests described.

The Tubes shall be standard quality lap-welded mild steel of standard manufacture. The thickness of the metal shall be 12 B.W.G. for 3-in. tubes, 11 B.W.G. for 3½-in. tubes and 10 B.W.G. for 4-in. tubes.

The Rivets shall be of boiler-rivet steel, as described in the standard specifications of the Association of American Steel Manufacturers and of proper size to suit the size of the hole and the thickness of the plates and to form up heads equal in strength to the pressed heads of same.

The Diagonal Braces shall be weldless, of the same quality as the flange steel previously described and pressed from the solid plate, or else forged from steel bars. The number of braces to be used shall be computed on an allowance of not more than 7,500 lb. of load per sq. in. of section of brace neglecting, in this, the inherent strength of the heads and the slight angularity of the braces.

Suitable Through Rods And Braces shall be installed below the tubes when necessary to sustain the pressure. These shall be of steel and shall be computed with the same allowance as diagonal braces.

Braces, as above described, shall be carefully placed so that the pressure on the flat surfaces, both above and below the tubes, shall be as nearly equally distributed as possible.

For Any Boiler Head The Area to be supported by braces shall (Sec. 241) be the surface included within lines drawn 2 in. from the outside of the tubes and 3 in. from the inside of the shell.

Design.—The longitudinal seam of the shell shall be of the butt-joint type (Sec. 236) having inside and outside covering strips, either double, triple or quadruple riveted as indicated in the Table. In all joints the size, number and spacing of the rivets shall be such as to provide the strength necessary to maintain the factor of safety of 5.

Boilers 44 in. or less in diameter shall have a manhole (Sec. 269) above the tubes and a handhole (Sec. 270) below the tubes. These may both be in the front head, or the handhole may be in the front head and the manhole in the back head. Boilers 48 in. in diameter shall have two manholes, both in the heads, one above the tubes and one below the tubes. They may both be in the front head, or one manhole may be in the front head below the tubes and the other in the back head above the tubes.

Boilers larger than 48 in. shall have two manholes, one of which shall be in the front end below the tubes; the other shall be above the tubes in either head, or, preferably, may be placed in the shell. The opening in the manhole shall not be less than 10 × 15 in.

All openings 2 in. in diameter or larger shall have suitable steel reinforcing flanges (Sec. 274) riveted on. Cast-iron flanges or nozzles shall not be used.

Boilers for 125 to 150 lb. working pressure shall have the feed opening in the front-head over the tubes and same shall be provided with a brass bushing and an internal feed-pipe (Sec. 315) extending from the front end of the boiler to within about 3 ft. of the rear-head, thence across to the side of the shell, terminating in an elbow for discharge below the top row of tubes. Boilers for 100 lb. working pressure shall be arranged to feed through the blow-off connection (Sec. 352) and the internal feed-pipe shall be omitted.

Each boiler shall be provided with four steel lugs or brackets, two on each side for supporting the boiler, except that boilers 78 in. in diameter or boilers 20 ft. long shall be provided with eight such lugs, four on each side of the boiler and all of them arranged in pairs.

WORKMANSHIP.—All rivet holes and all tube holes shall be either drilled from the solid plate or punched small and reamed to size. After drilling or reaming the plates shall be taken apart and all burrs removed and the tube holes chamfered with a rose reamer.

43. The advantages claimed for return-flue boilers in comparison with return-tubular boilers are as follows: (1) *Low first cost.* (2) *Entire surface more accessible for cleaning.* In fact the accessibility-for-cleaning feature is the only one which justifies the use of a return-flue boiler in a modern installation. The return-flue boiler is much less economical than the return-tubular or the water-tube boilers. But in applications where the only available feed water contains a large content of scale-forming impurities, return-flue boilers may prove economical. Boilers of this type are used on Mississippi river steam boats.

44. Prominent disadvantages of the return-flue boiler in comparison with the return-tubular boiler are: (1) Large-diameter flues diminish the area of heating surface that could otherwise be obtained. (2) The large-diameter flues are more liable to collapse than are small-diameter tubes. (3) The extra thickness of metal in the large-diameter flues renders them less effective in transmitting heat than are thin-walled tubes.

45. Distinct advantages claimed for the multi-tubular boiler are as follows: (1) It has the greatest evaporative capacity in proportion to its bulk of all fire-tube boilers which present an area of external heating surface. This is true whether the boilers are externally or internally-fired. (2) The water content is divided into thin currents circulating in contact with a multiplicity of tubes. Therefore, the tendency is that the heat of the gases will be transmitted simultaneously to all parts of the bulk of the water. Consequently, the boiler steams readily and responds promptly to overloads. (3) For a given extent of heating surface it is the least expensive of all boilers which have good evaporative efficiency.

46. Positive disadvantages usually charged to the multi-tubular boiler are as follows: (1) Its record for years past shows that it is more liable to explosion than the other types now in use. (2) The circular seams with their double thickness of plate are exposed to the direct action of the fire. This introduces an element of weakness. This disadvantage is shared in common by all externally-fired shell boilers. (3) The gases of combustion tend to short-circuit through the upper rows of tubes. This renders partially ineffective the heating surface presented by the lower rows. (4) Where the furnace is improperly designed, the gas currents are separated, by the multi-tubular arrangement, into finely-divided streams. Hence, with a poorly-proportioned furnace, the long tongues of flames from bituminous coals of a very-gaseous character become extinguished immediately when they enter the constricted tube areas. Consequently, the incompletely-burned gases escape as smoke and the incandescent carbon particles which are mixed with the flaming gases are deposited as soot. However, this disadvantage is one of furnace rather than of boiler design. (5) The water surfaces of the tubes are difficult of access. (6) Crowding of the water space with tubes tends to impede circulation.

47. The service for which the return-tubular boiler is fitted is really a matter of economics. For some services it may be the most economical type, but for others it may not. The first-cost per boiler horse power is very low. These boilers, have for this reason, been used extensively, even in

situations where an analysis of the conditions on an annual operating-cost basis would not justify their installation. Ordinarily, they are not built for steam pressures greater than 150 lb. per sq. in., or for capacities greater than 200 boiler h.p. Hence, they are utilized largely in small hand-fired plants. Experience has shown that the metal in the shell immediately above the fire, should not exceed a certain thickness. If it is made too thick, the plates deteriorate quickly, due to overheating and the consequent crystallization. This limitation of plate thickness determines the maximum pressures and capacities for which the boilers should be built.

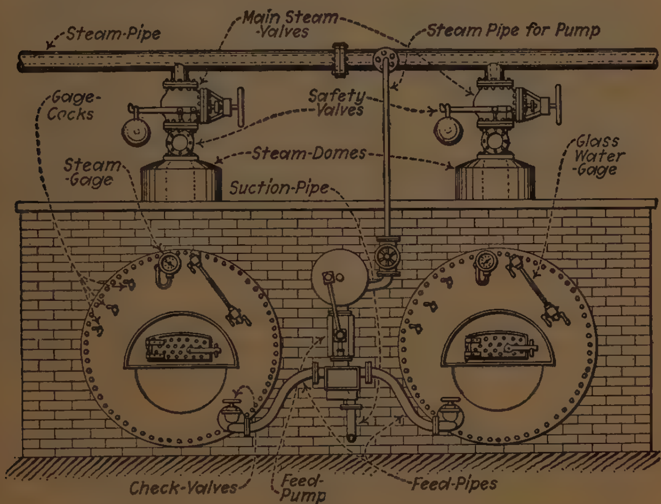


FIG. 41.—Front-end view of a pair of Cornish boilers.

Return-tubular boilers are not suited for installations where the only available fuel is coal of a very gaseous character, that is, coal which burns with a long streaming flame. They give better service with caking (Sec. 415) and cannel coals. Neither are they adaptable for large chain-grate-stoker installations designed for burning fuels of very low grades.

48. Internally-fired flue boilers may be roughly divided into two classes, thus: (1) *Those requiring a setting of masonry* (Figs. 41 and 42) for the reason that the heat of combustion is absorbed partially by external surfaces. (2) *Those which*

are self-contained and hence require no setting, because the heating surface is entirely within the outer shell.

49. The Cornish Boiler Is The Oldest Design Among Modern Internally-Fired Boilers.—The present-day Cornish boiler

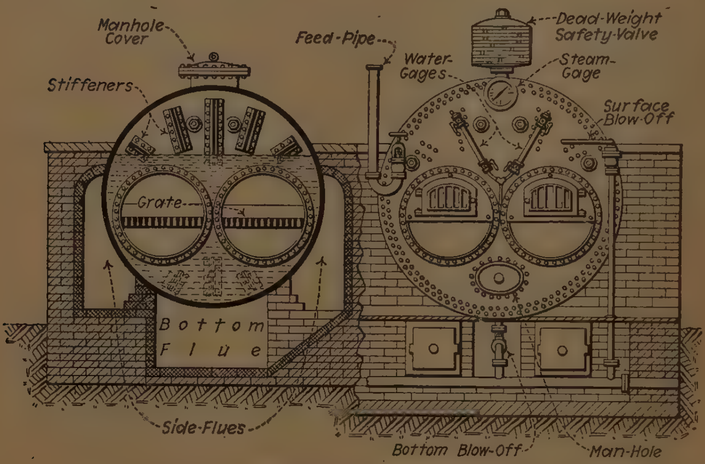


FIG. 42.—Front-end and cross-sectional views of a pair of Lancashire boilers.

(Fig. 41) is identical in its main features with the first of its kind (Fig. 18). It is seldom, if ever, now installed in the United States. Its use is, however, common in England.

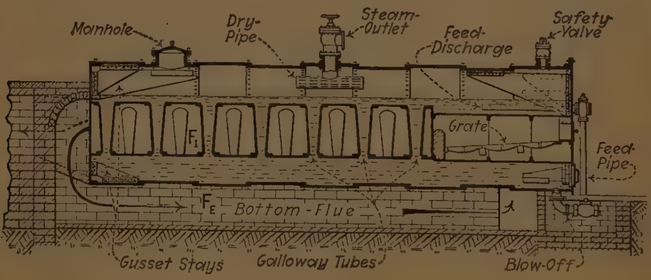


FIG. 43.—Longitudinal section of Galloway boiler and setting.

50. The Lancashire or Double-Cornish boiler (Fig. 42) is merely a development of the original Cornish principle. The main difference is that the Lancashire has two flues instead of one.

51. The "Galloway" or "Breeches" boiler (Figs. 43 to 46 inclusive) are the names popularly given to the modern style of Lancashire boiler. These designations follow from

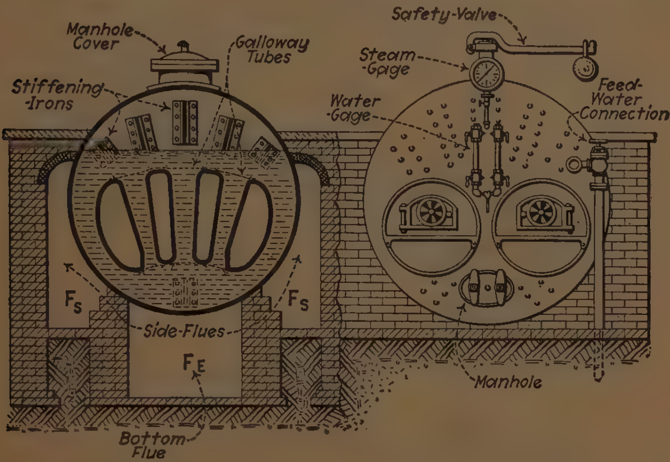


Fig. 44.—Views of front elevation and of cross-section through kidney flue of Galloway boiler.

the fact that the furnace tubes merge just beyond the bridge-wall into one large kidney-shaped flue (Fig. 46) which is traversed radially (Fig. 45) throughout its length by conical

Fig. 45.—Galloway tubes in circular flue. (Large diameters of tubes are at top.)

water tubes. These *Galloway tubes* (Fig. 45) are inserted to increase the heating surface and to promote circulation. Furthermore, they brace the flue.

52. The dry-back variety of the Scotch boiler (Fig. 47) combines certain intrinsic features of the standard multi-tubular and the Cornish types shown in Figs. 36 and 41. It should, since it requires an external masonry back-connection, be classed with the first variety of the externally-fired boilers mentioned in Sec. 48. It is an adaptation, for stationary plants, of the type of boiler popular in marine service, in which compactness is a prime consideration. It is a quick-steaming boiler, occupies small space for the power developed and shows a good economy.

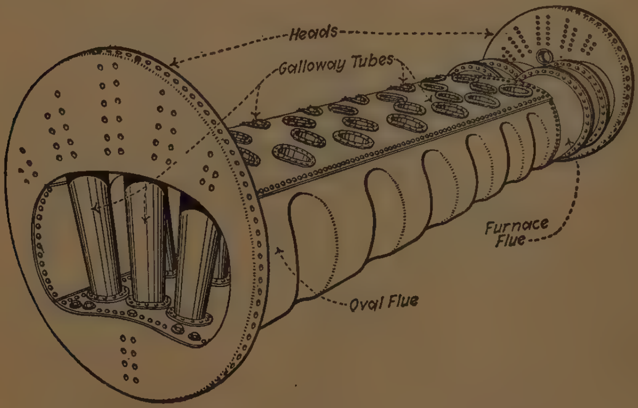


FIG. 46.—Galloway boiler with outer shell removed.

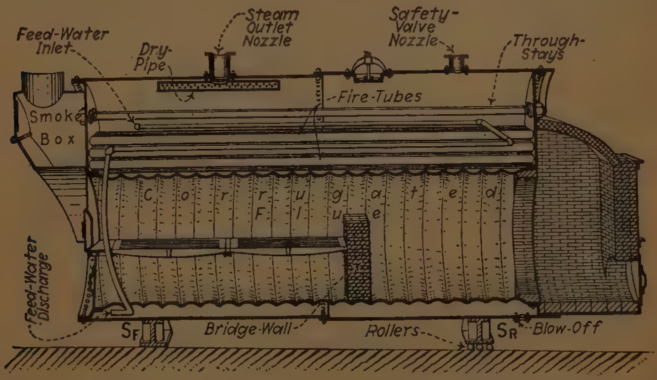


FIG. 47.—Sectional view of Freeman internally-fired-multitubular boiler.

53. The construction of the dry-back Scotch boiler is shown in Fig. 47. The furnace-flue is corrugated to provide maximum strength. The shell rests in saddles, S_F and S_R, Fig. 47. The rear saddle, S_R, usually rides on rollers which are so

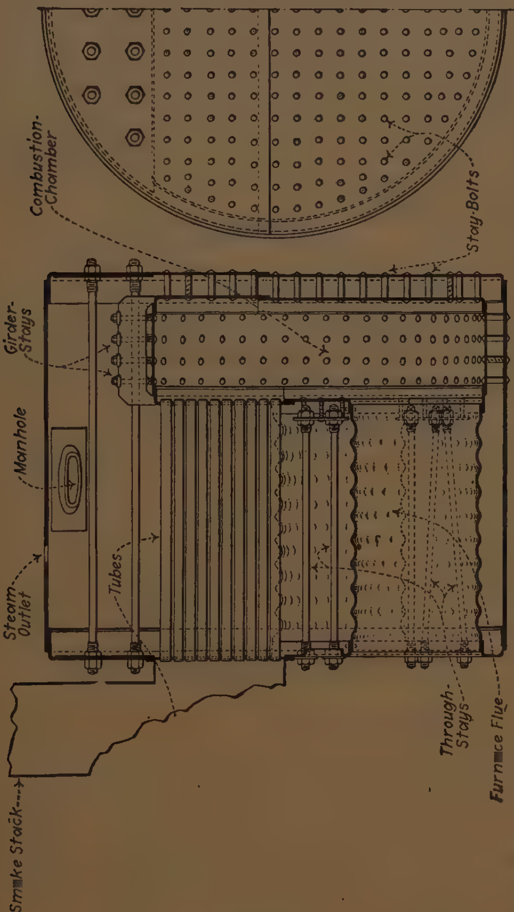


FIG. 48.—Sectional elevation lengthwise of Scotch wet-back boiler. (S. Freeman & Sons Co.)

placed as to permit free endwise expansion. By making the back-connection external to the boiler (instead of an inseparable part of it, as in the true Scotch boiler, Fig. 48), the construction is much simplified. Also the interior of the boiler is thereby more accessible for cleaning. Furthermore,

the necessity for bracing much additional flat surface is eliminated. These boilers are now used to a considerable extent in the United States for temporary installations. They can be transported readily and installed at small expense.

54. The true form of Scotch or drum boiler has the water back construction. It is shown in Figs. 48, 49 and 50. This belongs to the second variety of internally-fired boilers (Sec. 48) since it is entirely self-contained and, therefore, requires no setting. It was developed to satisfy the demand for a very compact absolutely self-contained boiler. Since these boilers occupy, probably, less volume per unit of power

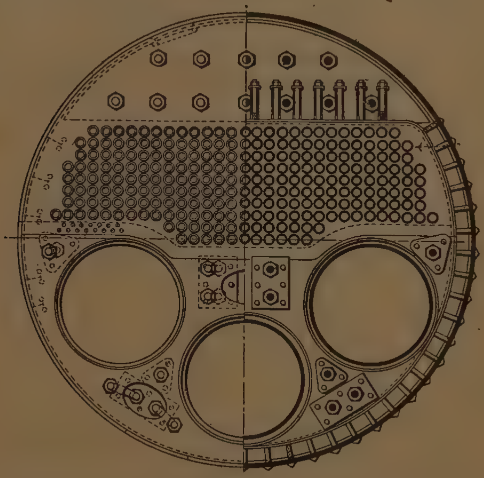


FIG. 49.—Semi-front and cross-sectional elevations of Scotch boiler.

developed than those of any other type, they are installed in locations where space is very valuable. In the past they have been used widely in marine service, but more recently have been superseded by water-tube boilers of modern design.

55. The construction of the Scotch marine type boiler is detailed in Figs. 48 to 50 inclusive. They have been built with external shells of diameters up to 20 ft. The usual diameter is from 10 to 15 ft. and the length from 7 to 11 ft. From two to four furnace flues are used. The flues are short and of relatively large diameter. The grate bars are set just below the horizontal diameter of each flue. The furnace

gases pass into a combustion chamber at the rear. Thence they flow through groups of small flue-tubes to the chimney up-take at the front end. The safety of this boiler is determined largely by the care that is exercised in staying the extensive areas of flat surface which are presented by the combustion chamber and the external heads. The back sheet of the combustion chamber is secured to the external head with stay bolts. The front sheet is stayed by the furnace flues and tubes. The front and rear head areas above the

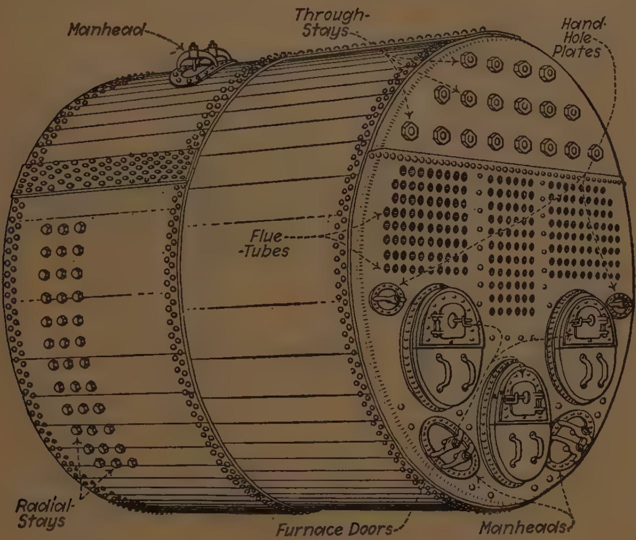


FIG. 50.—External view of typical Scotch boiler.

tubes and combustion chamber are also bonded together with through stays. The top sheet of the combustion chamber is braced with girder stays.

56. The leading advantages of the Scotch boiler may be enumerated thus: (1) It occupies the least volume as compared with the power developed of any boiler suitable for general power plant work. (2) Its free-steaming characteristic renders easy the maintenance of a uniform steam pressure under a varying load.

57. The principal disadvantage of the Scotch boiler is the tendency of the water in it to circulate sluggishly in the

region below the furnace flues. This results in the contiguous area of the shell plate remaining relatively cool. Thus strains due to unequal expansion are generated.

58. Internally-fired boilers patterned after the fire-box type which is used in locomotive design (Fig. 51) are employed largely for portable and semiportable applications. They are used with transient agricultural and saw-mill outfits and under similar conditions. Occasionally they are found in stationary plants.

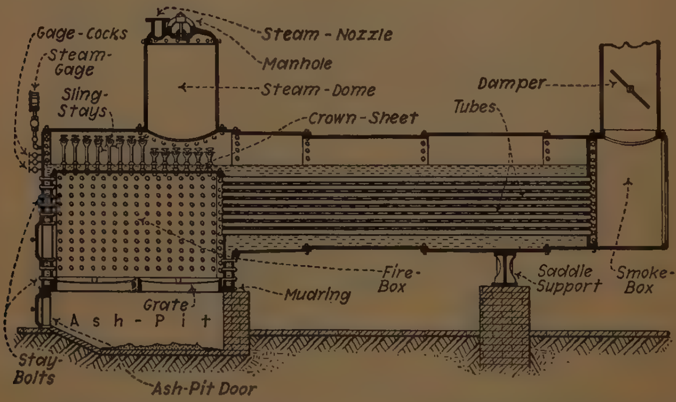


FIG. 51.—Sectional view of locomotive type of boiler as used in stationary practice.

59. The construction of the locomotive-type boiler is shown in Fig. 51. It contains a rectangular fire-box having water-legs formed, on its sides and ends, by the vertical sheets of an outer box-like construction which encloses the fire-box at the sides, front, and rear. The side-sheets, top-sheet and rear-sheet of the outer box are attached to a cylindrical shell which is filled with flue-tubes. Through these tubes the products of combustion flow directly to the stack. The tubes extend from the rear or tube-sheet of the fire-box to the head of the shell. They are expanded into bored holes at each end. The bottoms of the water legs are closed by riveting the inner and outer sheets to a heavy flanged mud-ring. Or, the inner sheet may be flanged outward and downward to form a riveted joint with the outer

sheet. The top of the fire-box is flat or slightly arched. It is braced with stays secured to the forward extension of the top half of the shell or "wagon top" as it is sometimes called. The grate-bars rest on angles which are fastened with stud-bolts to the front and back fire-box sheets. Ordinarily, the ash-pit or pan is separate from the fire-box. But sometimes (Fig. 52), it is formed by providing bottom-sheets for the fire-box and its external envelope. In this construction, the vertical

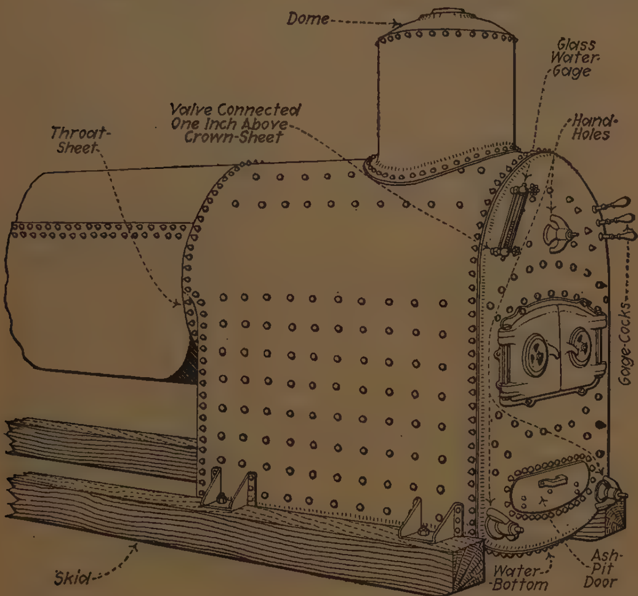


FIG. 52.—Fire-box end of locomotive-style of stationary boiler with water bottom.

water-leg around the fire-box merges with a water-bottom, as the space between the inner and outer bottom-sheets is called. The fire-box is entirely surrounded by water, except for the fuel and ash-pit openings.

60. The tubes of a locomotive-type boiler for stationary service are fewer in number, but larger in diameter, than those for a boiler intended for railway service. In a locomotive, quick steaming takes precedence over other desirable qualities. Diameters of 3 and 4 in. are good sizes. The large

tubes reduce the heating surface but conduce to better water circulation.

NOTE.—THE "DUPLEX" BOILER (Fig. 53) combines the salient features of the Cornish, the fire-box and the multi-tubular types.

61. The principal merits claimed for boilers of the locomotive fire-box and kindred types are: (1) *Compactness.* (2) *Great steaming capacity.* (3) *Fair economy.* (4) *Mobility.*

62. The objectionable features most prominent in fire-box boilers are: (1) *The great extent of flat surface which requires bracing.* (2) *The sluggishness of water circulation, which their arrangement of parts induces.* (3) *The liability of corrosion in the water-legs on account of sedimental deposits.* (4) *The difficulty of reaching the inside for cleaning.*

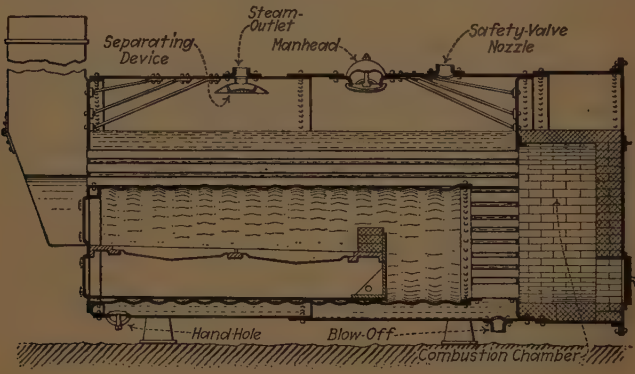


FIG. 53.—Sectional view of "Duplex" boiler.

63. A vertical form of fire-box boiler which is well adapted for construction outfits in connection with hoisting engines, is shown in Fig. 54. It is much used for temporarily-located plants, since it occupies but little space, is readily maintained, and easily transported.

64. As to construction, the fire-box of a vertical boiler is made with a flat top or crown sheet and usually with a cylindrical ring sheet roundabout. But sometimes it is built with a ring sheet formed like a truncated cone, as shown in Fig. 54. A nest of flue tubes extends from the crown sheet to the head sheet of an external cylindrical shell. The tubes are usually

2 in. in diameter. An annular water-leg, closed at the bottom with a forged wrought-iron mud-ring (Fig. 54), or by flanging the fire-box sheet to meet the shell in a riveted joint (Fig. 55), surrounds the fire-box. The fire-box is stayed to the shell with screwed stay bolts. The tubes serve to stay the crown sheet and the external head. The boiler is set on a cast-

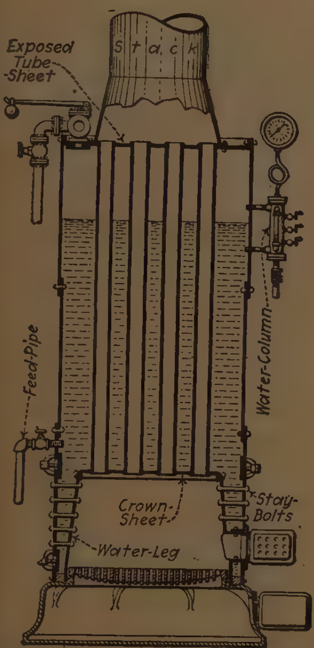


FIG. 54.—Semiportable upright fire-tube boiler having non-submerged tubes.

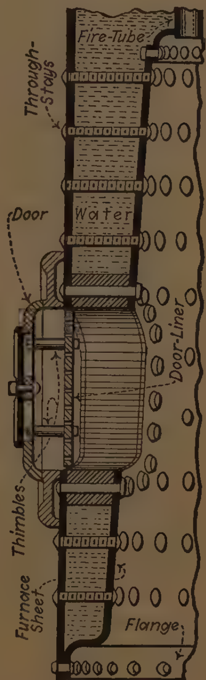


FIG. 55.—Furnace sheet flanged to close water-leg at bottom.

iron base which contains the ash-pit. Usually the grate bars are supported by an enclosed iron ring fastened to the furnace sheet with studs just above the mud ring. Sometimes, however, they rest on the base (Fig. 54).

65. A Common Defect Of Upright Boilers Is Over Heating Of The Unprotected Tube-ends Above The Water Line.—This may result in a loosening of the beaded joints between the tube ends and the tube sheet. To overcome this difficulty,

these boilers are often built (Fig. 56) with a submerged tube-sheet. The heavier material and construction of the depressed smoke connection, which is required with this method, are better adapted to resist distortion from overheating than are the relatively-light tube-ends of Fig. 54.

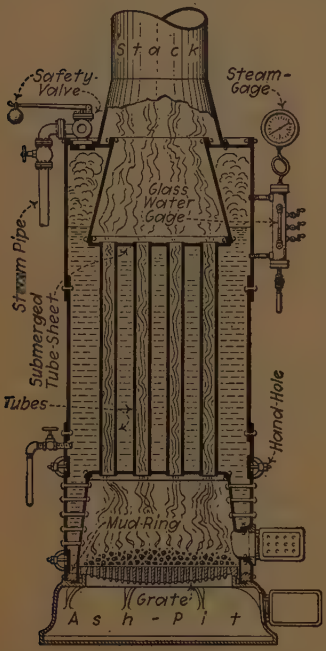


Fig. 56.—Upright boiler with submerged tubes.

Note.—Great Care Should Be Exercised In Raising Steam In An Upright Boiler. The fire should be kindled gradually until steam contacts with the unprotected tube ends above the water line. Never use oily waste or other highly-combustible substance in starting a fire in an upright boiler. These will overheat the top sheet and likely cause a leak. The submerged-tube type (Fig. 56) is much more reliable in this respect than is the non-submerged-tube type (Fig. 54).

66. Objections to the vertical fire-tube boilers are as follows: (1) *The steam-liberating surface is small.* In the submerged-tube design, the bubbles tend to huddle under the tube sheets. There they form small pockets of steam which produce a geyser-like action in their passage from the water. The result is priming and wet steam. (2) *The water circulation is indeterminate and sluggish.* (3) *Forced firing may cause damage to the crown sheet.* This is on account of the extremely rapid evaporation of the water in contact with the sheet. (4) Its operation is apt to involve an element of danger, since it contains the least quantity of water in proportion to its steaming capacity of any of the shell boilers. (5) *As ordinarily built the short travel of the furnace gases renders it very wasteful of fuel.* (6) *Access to the water legs for cleaning is difficult.* (7) *Corrosion of the shell* is rapid around the firing door and

also below the grates and around the bottom seam at which locations ashes accumulate.

67. The principal merits of the vertical fire-tube boiler are as follows: (1) *It is a rapid steamer.* Its vertical heating surface gives a decided advantage in this regard. (2) *Since it occupies but little space and is transported readily, it is well adapted for temporarily-located plants.* See Sec. 648 for suggestions as to suitable applications for vertical fire-tube boilers.

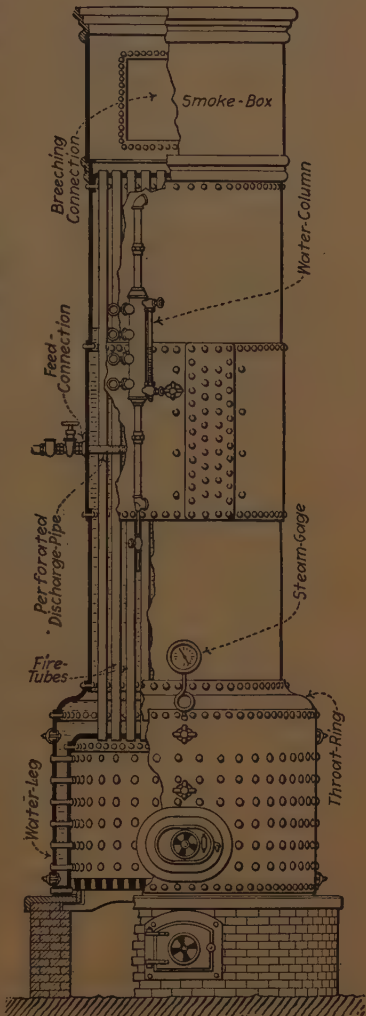


Fig. 57.—Manning vertical fire-tube boiler.

68. A Manning vertical fire-tube boiler designed for installation in stationary plants where the available floor space is scant is illustrated in Fig. 57. It is set either on a brick foundation with the ash-pit built in, or on a cast-iron base which rests on a masonry foundation. The fire-box is made larger than in boilers of the portable type. This is effected by increasing the diameters of both of the circular sheets which form the water legs. The enlarged section of the external shell is joined to the smaller section above by a double-flanged throat ring. Comparatively-small tubes—generally of 2½ in. diameter—are used. They range in length from 12 to 15 ft. The tubes are grouped in four

nests (Fig. 58). There is ample cleaning space between. The spaces afford convenient access for washing the top of the crown sheet through hand-holes in the shell. A perforated extension of the feed pipe inside the boiler delivers the water in finely-divided streams, among the tubes.

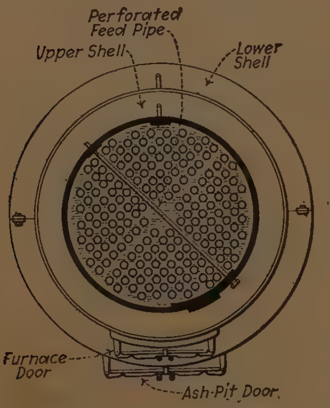


FIG. 58.—Cross-section of tubes in Manning boiler.

69. The advantages claimed for the Manning boiler over ordinary boilers of its class are as follows: (1) *A proportionately larger grate area,* thus permitting a slower combustion rate for a given evaporative effect. (2) *Greater tube length* gives flexibility under stress of expansion. This permits the upper ends of the tubes to serve as superheating surface without detriment to the tube sheet joints. (3) *The offset in the external shell serves to isolate the stresses in the upper and lower sections.* (4) *Better facilities for cleaning.*

70. A sectional boiler (see Fig. 59 for an example) is defined as a steam-generating unit in which a number of small generating chambers or unit sections are joined together in such a manner that the steam formed in all of them is carried by the water currents to a common disengagement surface, from which the steam passes into a common storage or steam space. The double cylindrical boiler (Fig. 30) and the elephant boiler (Figs. 31 and 32) may be regarded as marking the first step in the development of the sectional principle. The ultimate development is exhibited in the various forms of water-tube boilers now in use.

NOTE.—The sectional principle in boiler design may be amplified by so dividing the area for steam disengagement that the steam issuing from several small disengaging areas is delivered to a common steam drum.

71. The advantages of the sectional principle in the design of steam boilers (this applies, in general, to all water-tube

boilers) are as follows: (1) *A boiler can be constructed for a given evaporative capacity with a less weight of metal than would otherwise be advisable.* This result rests on the fact that the strength to resist rupture with a given internal pressure, increases as the diameter of the shell or tube is diminished. (2) *The thin metal exposed to the products of combustion affords a more rapid transfer of heat* from the fireside to the water side than where the principal area of heating surface

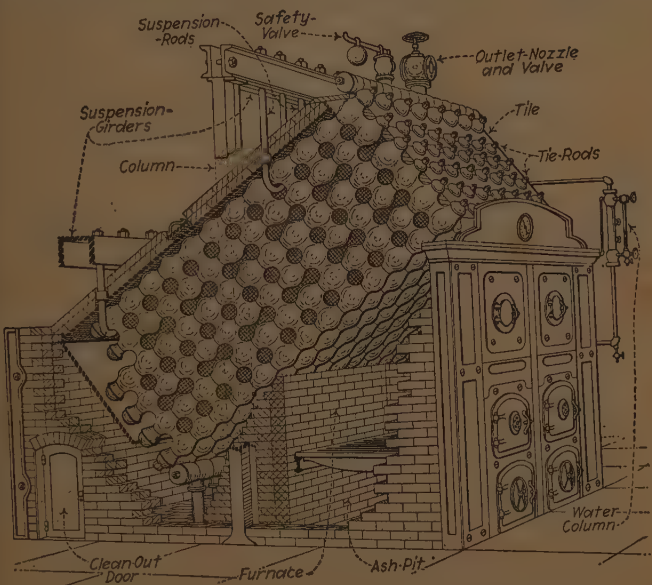


FIG. 59.—The Harrison spherical section boiler. (This type is no longer built.)

is presented by thick shell plates. (3) *Failure of any single section from over-pressure or deterioration will not result in disaster to the entire structure.* The defective section will act as a local vent or outlet. Thus, it will prevent an instantaneous release of pressure from the mass of contained water. Therefore it will prevent the other sections from becoming involved in a serious over-strain. (4) *The sectional construction renders the boiler more portable than are ordinary shell boilers.* Likewise they are more conveniently erected in situations which are difficult of access. The true-sectional

boilers may be shipped "knocked down" and assembled piece by piece. (5) *Repairs and renewals of sections can be made cheaply, easily, and rapidly.* Usually they can be effected with ordinary labor and skill obtainable in the boiler room. (6) *The total volume of metal upon which the flame and hot gases impinge is less than with shell boilers of any of the types.* (7) *Sectional boilers will stand being driven further beyond their normal capacities without impairment, than will shell boilers.* Modern sectional boilers will work under a steady overload of 50 per cent. For shorter intervals, they may be worked at 200 per cent. or even at greater overloads, see Secs. 405 and 650.

72. The disadvantages charged against the sectional principle in boiler construction are as follows: (1) *Proper access to the interiors of the sections often involves the use of two openings for each section.* This entails a multiplicity of either ground or gasket joints. (2) *Unequal expansion and contraction under stresses of service operates to produce distortion* by twisting and bending the rigidly-connected sections. This tends to cause straining and loosening of the joints. (3) *Priming and the appearance of a fictitious water level in the glass water gage* on account of tumultuous disengagement of the steam bubbles. This results from the disengagement area being confined to that part of the water surface which is immediately above or adjacent to the orifices through which the water and steam bubbles ascend from the sections into the common water and steam space. (4) *The narrow channels which the steam bubbles must traverse in passing from the generating surfaces of the sections to the common disengagement surface.* To compensate for the restriction thus imposed, an extremely high velocity of circulation is required. To establish a sufficiently high velocity is difficult. If the circulation is not sufficiently rapid, displacement of small bodies of water by steam pockets forming in the sections will inevitably occur. Such displacement will expose areas of the metal to overheating and oxidation. (5) *Impossibility of visual inspection throughout the entire interiors of such sections as are made with bent surfaces.* (6) *The great number of connections require more maintenance* to keep the boiler tight. Because of the relatively-great number of connections, mainte-

nance-cost is high. (7) *Special details of workmanship and complexity of parts* result in high initial cost. Per unit of capacity, the sectional-water-tube boilers cost 50 to 100 per cent. more than shell boilers.

73. The conventional rating of sectional boilers is 1 h.p. for from 10 to 12 sq. ft. of heating surface. It is usually assumed that they have an evaporative rate of from 10 to 12 lb. of water per lb. of combustible. See Sec. 404.

74. The Babcock & Wilcox boiler, a typical example of the water-tube sectional type (Fig. 60), was the first successful

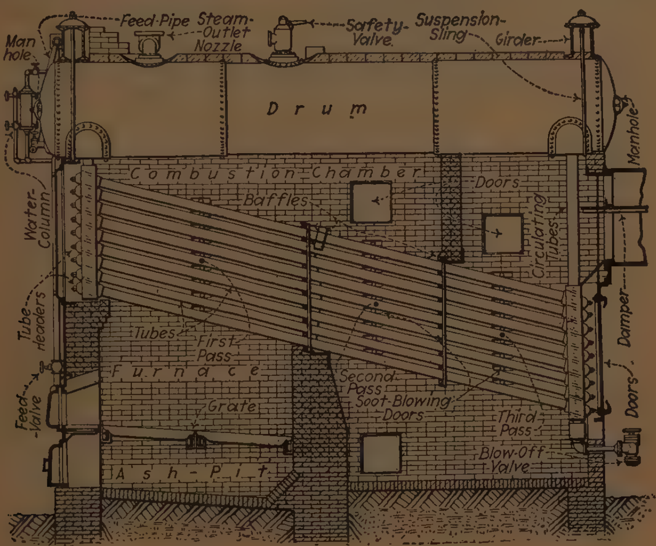


FIG. 60.—Babcock & Wilcox boiler with cast iron headers.

boiler of this class. Its characteristics are the horizontal drums and inclined tubes. The sectional feature is shown definitely (Fig. 61) in the grouping of the inclined tubes. Each nest of tubes is divided into staggered vertical rows. The tubes of each row are expanded into holes, bored in a header (Fig. 62 and 63) at each end. These several headers (Fig. 60) are connected above to one or two drums by vertical or slightly-inclined tubes. The rear bank of headers is connected below, by short expanded nipples, with a mud-drum

which extends entirely across the setting. The complete boiler structure is hung from a steel supporting frame which is entirely independent of the brick-work.

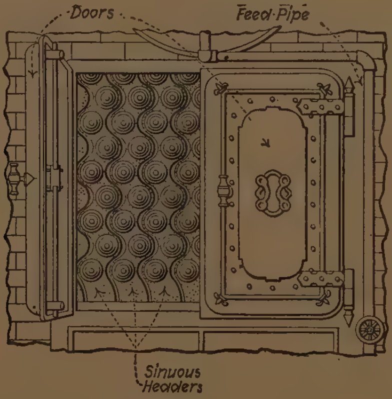


FIG. 61.—View showing sinuosity of headers.

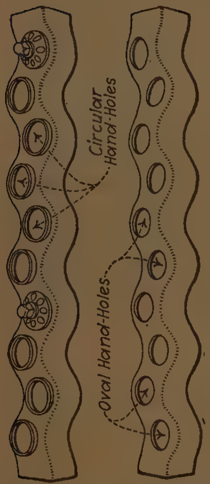


FIG. 62.—Wrought steel headers with elliptical and circular hand-holes.

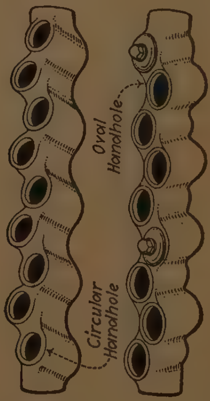


FIG. 63.—Cast iron headers with elliptical and circular hand-holes.

75. The tubes of the Babcock & Wilcox boilers are usually 4 in. in diameter and 18 ft. long. The entire nest (Fig. 61) may consist, in the 100-h.p. boiler, of 6 vertical sections

containing 9 tubes each. In the 500-h.p. boiler, there may be 18 sections of 14 tubes each. In the 2300-h.p. boiler there may be 51 sections of 20 tubes each.

NOTE.—But the sections are so arranged that a wide choice, as to number of sections and number of tubes per section, is possible for any given horse power rating. This is a decided advantage where the head room or width available for the installation of the boiler is limited.

76. The drums of Babcock & Wilcox boilers are made of steel plate. Boilers of ratings under 150 h.p. have one drum. Those larger have two. The headers are of sinuous form (Figs. 61, 62 and 63) to accommodate the staggering of the tubes. They may be of cast iron (Fig. 63) for boilers operating at a pressure of 160 lb. per sq. in. or lower, and of forged steel (Fig. 62) for greater pressures. However, boiler codes and the statutes in certain localities, prohibit the use of cast-iron headers for any pressure whatsoever. In such situations, wrought steel must, of course, be employed. The mud-drum is of wrought steel.

77. Hand-holes are provided in Babcock & Wilcox boilers opposite each tube end (Figs. 64 and 65) to permit the clean-

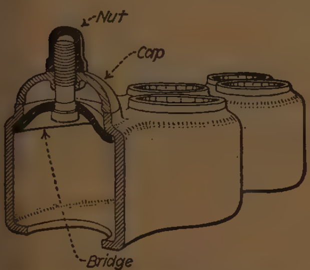


FIG. 64.—Circular handhole in wrought steelheader.

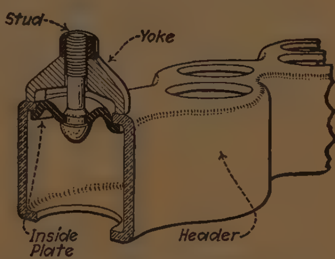


FIG. 65.—Fittings for elliptical hand-hole in wrought steel header.

ing and renewal of the tubes. The handhole may be either circular or elliptical. The elliptical handholes are used in vertical headers (Fig. 60) because of the inclination of the tubes. This shape is necessary to provide for their insertion and removal. Circular handholes are used (Fig. 66) in those headers which are connected at right angles to the tubes. The elliptical handhole in a wrought-steel header is closed by an

inside plate (Fig. 65), held with stud and yoke. The joint is made with a thin gasket. When circular, the handhole is surrounded by a raised seat. It is closed by a cap which makes a ground joint with the seat. It is secured (Fig. 64) by a bolt. This clamping bolt is ball-headed, to permit free adjustment of the parts to one another, and is pulled tight with a nut which is ground metal-to-metal with the cap. The cap and nut are of forged steel or cast iron, according to which of these materials is used for the headers. In the cast-iron header, outside caps are employed for both elliptical and circular holes.

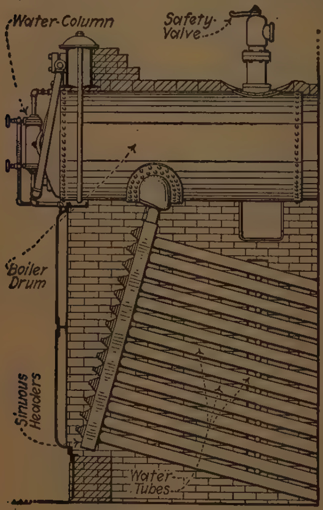


FIG. 66.—Inclined-header of B. & W. boiler.

78. Two baffles are provided in Babcock & Wilcox boilers to distribute (Fig. 60) the hot gases of combustion over the heating surfaces. Finally, the gases pass out, through a damper-box in the rear wall, and enter the chimney flue. Or, otherwise, they flow up around the drums and pass out through a damper-box located above, instead of below, the drums. The three gas-passages through the tubes, which are thus formed by the baffles, are conventionally called the *first*, *second* and *third* "*passes*." These are formed of cast-iron plates, clamped to the tubes and lined with plastic fire brick. The front baffle deflects the products of combustion upward through the first passage of the tubes to a chamber beneath the drum or drums. From this location, the gases are directed downward, by a hanging bridgewall, through the second passage of the tubes. Thence, they flow beneath the lower edge of the rear baffle and upward through the third passage.

79. A class of sectional water-tube boilers having inclined tubes connecting at each end into a water-leg pendant from a horizontal or nearly-horizontal drum is exemplified by the

Heine, O'Brien, Murray, Keeler, Edgemoor and certain other designs. While sectionalization is not, in boilers of this type, carried as far as in those of a construction similar to that of the Babcock & Wilcox boiler, it is claimed by the advocates of the water-leg construction, that the water-legs provide more effective circulation. The water-legs are riveted to and form integral parts of the drum.

80. The Heine boiler (Fig. 67) has inclined tubes connected front and rear to a parallel drum or drums which are located above. The drums and the tubes lie, pitching downward, at a relatively-small angle with the horizontal. The

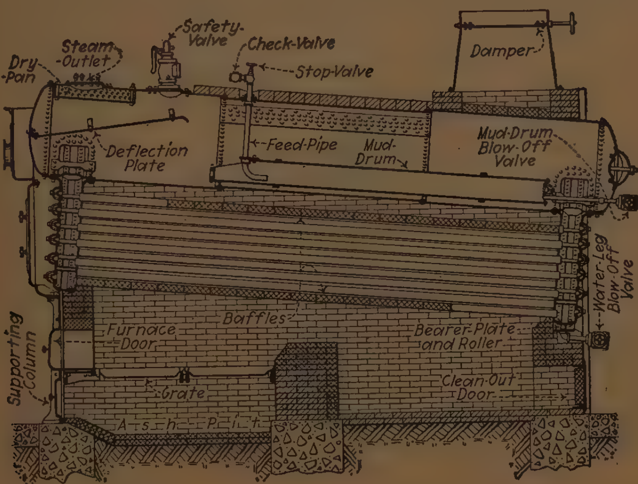


FIG. 67.—Longitudinal section of single-pass Heine boiler.

small boilers have one drum. The larger boilers have two drums, which are placed side by side. In diameter, the drums vary from about 30 to 48 in. and in length from 17 to 22 ft. The tubes are expanded at each end into a water-leg made of heavy steel plate.

81. The water-legs of the Heine boiler form rectangular boxes. They have flanged semi-circular throats to provide for the riveted connections with the drum or drums. The tube and handhole sheets of each water-leg are tied together with hollow stay-bolts.

82. The handholes in the water-leg of the Heine boiler (Fig. 68) are usually circular. They are closed, ordinarily, by cast-iron or drop-forged steel plates, which are inserted inside the water-leg from a few conveniently-placed master holes of oval shape. Lead or asbestos gaskets seal the joints. Yokes and bolts hold the handhole plates in position. Or the "key" handhole cap may be used instead.

83. The key safety handhole cap (Fig. 69) is a recently-developed device for closing these circular handholes. It is

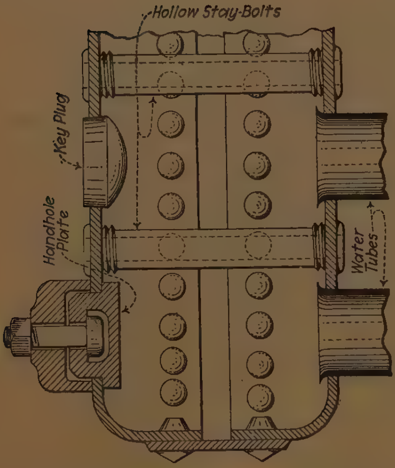


FIG. 68.—Section of lower part of water-leg, showing ordinary cast iron and also key handhole plugs in place.

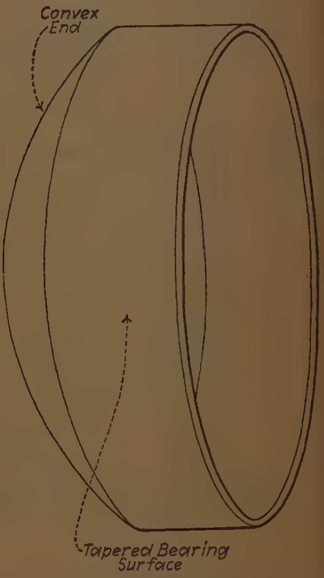


FIG. 69.—The key safety handhole plug.

formed from 1/8-in. steel plate, which has the chemical and physical properties prescribed for flange steel. Prior to the first application of the caps, the handholes are formed to a uniformly-smooth surface and given a slight taper by the use of a special roller tool. The bearing surface of each hole is coated with graphite. The caps are slipped into place (Fig. 68) from the inside of the water-leg. The circumferential shell of each cap is then rolled out with a special tool to snug

contact with the taper of the hole. The steam pressure holds the cap firmly to its seat. Subsequent rolling of the cap is unnecessary. The initial rolling gives its periphery the true circular contour, which it will retain indefinitely unless deliberately mauled out of shape. A hammer blow on the protruding edge of the cap will, when the boiler is cold and empty, remove it.

84. The setting arrangement of the Heine boiler is shown in Fig. 67. Ordinarily the front leg of the boiler rests on two

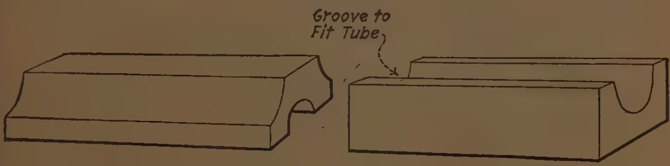


FIG. 70.—Typical tile forms used in baffles of water-tube boilers.

cast-iron columns. One is located on each side of the furnace. The rear leg rests on a cast-iron plate (Fig. 67) which is set in the masonry. Rollers are interposed between the water-leg and the bearing plate to allow for free expansion of the structure.

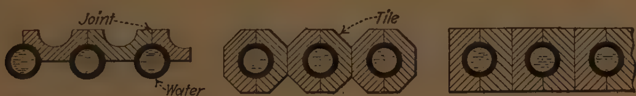


FIG. 70*A*.—Showing arrangement of tiles and tubes.

85. The travel of the gases of combustion in the Heine boiler is parallel to the tubes. The boilers of small size are so baffled as to pass the gases but once through the nest of tubes as indicated in Fig. 67. Boilers of capacities greater than 500 h. p. are generally baffled so as to insure two passes (*A* and *B*, Fig. 70*B*) of the gases parallel to the tubes.

NOTE.—IN BAFFLING HEINE BOILERS the bottom baffle is made up of C-tile or box-tile (Figs. 70 and 70*A*), if it is desired to entirely cover the lower row of tubes; T-tile are used when it is desired to expose the lower half of the tubes. The choice of the type of tile usually is determined by the operating conditions. The lower baffle usually extends to within 36 to 48 in. of the rear water leg. The top baffle is generally made up of

T-tile, is flush with the rear water leg, extends to within 30 to 36 in. of the front water leg and rests on the top row of tubes.

In the two-pass Heine boiler the middle baffle is placed on the middle row of tubes flush with the rear water leg and approximately 36 to 48 in. from the front leg. This baffle is usually of cast iron because of the wearing qualities of this metal. The middle baffle is difficult to repair after the boiler has been bricked in. The cast iron baffles are provided with lugs so that they can be removed, through the top row of tubes, with a hook.

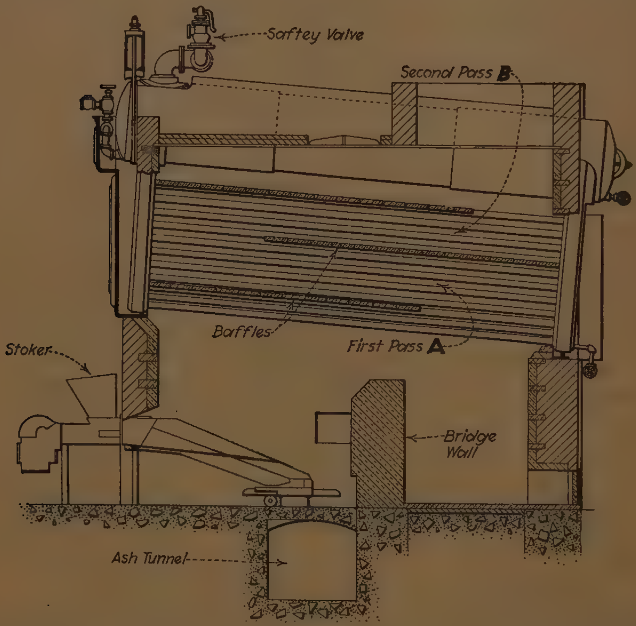


FIG. 70*B*. Longitudinal section of a Heine two-pass boiler as set with underfeed stokers of the Taylor, Riley, or Westinghouse types. (Tiles are placed on the third row of tubes.)

The top baffle in the two-pass boiler is so placed as to leave the wide opening at the rear water leg. A space approximately 6 in. wide is usually provided at the front end to assist in eliminating the dead pocket of gas which would otherwise collect there. The question of proper baffle opening is a much-debated one: The proper size for the opening can, apparently, only be determined by experiment and by giving proper consideration to draft, operating conditions and combustion analysis.

86. A Recent School of Boiler Design Adopted the Vertically-Inclined Tubes (Fig. 71).—About thirty years ago there was

developed a class of steam-generating apparatus which embodied some radical departures from the structural principles then prevailing. Instead of adhering to the provision of a nest of horizontally-inclined tubes attached through intermediate headers or water-legs to horizontal or nearly-horizontal drums above, this new design provided vertically-inclined tubes connecting directly to drums above and below.

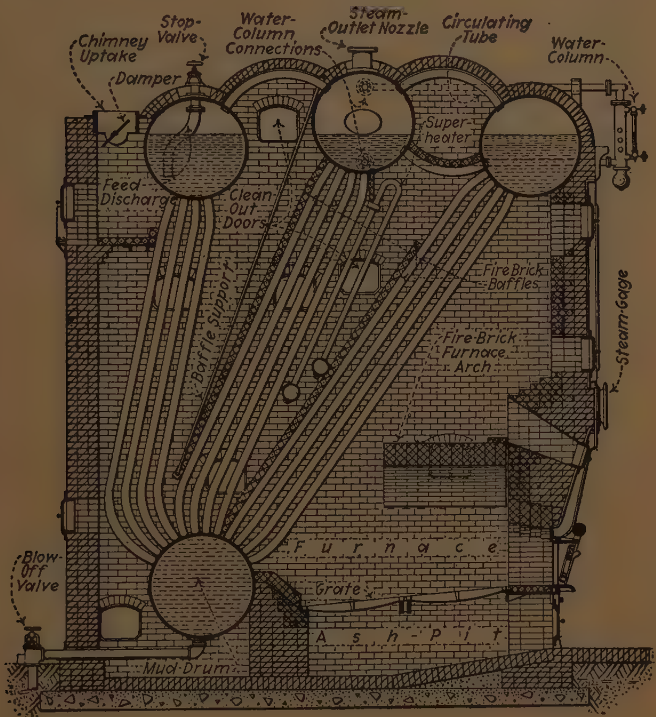


FIG. 71.—Sectional side elevation of Stirling water-tube boiler.

The Stirling (Fig. 71), the Bigelow-Hornsby (Fig. 72), the Connelly, the Badenhausen, and others are constructed in conformity with this general design.

87. The Stirling water-tube boiler (Fig. 71) is one example of a number of successful boilers of the vertically-inclined-tube class. This boiler comprises three upper steam drums, each connected by a bank of tubes to a lower mud-drum. The

tube ends are, where necessary, curved to enter the drums radially. They are expanded into reamed holes in the drum shells. Drums vary from 36 to 54 in. in diam., as determined by the capacity of the boiler. Sets of short arched circulating tubes located above, interconnect the

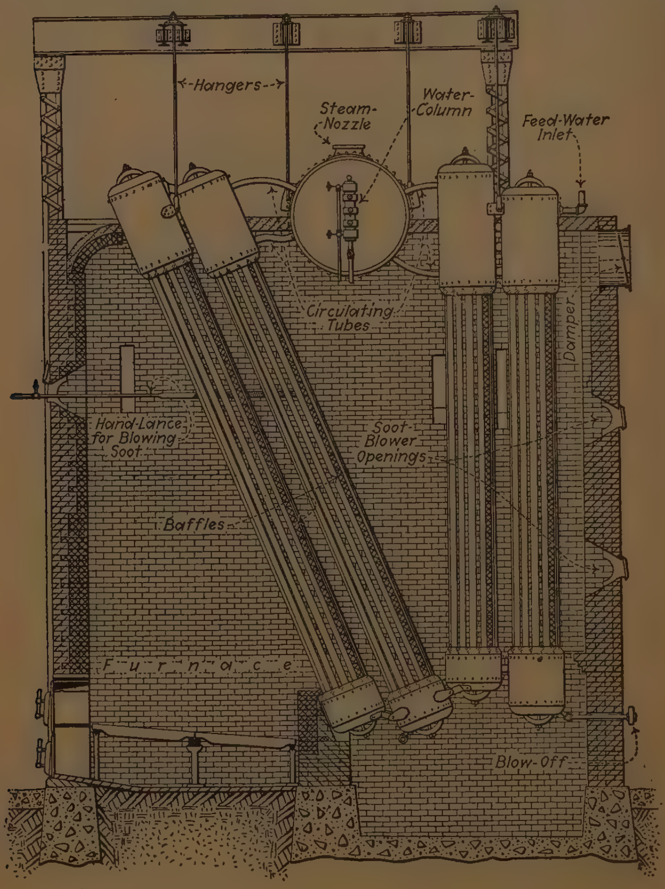


FIG. 72.—Side view of Bigelow-Hornsby water-tube boiler.

steam spaces of all three of the upper drums. A smaller set of tubes, located below, connects the water spaces of the front and middle drums. The feed-water enters the rear upper drum. The units are arranged in sections. The

entire boiler structure is hung from the three upper drums, each of which rests in iron saddles. The iron saddles are supported by a structural steel frame which is independent of the brick setting. Thus the mud-drum is hung suspended on the tube-ends. It is entirely free of the frame and masonry work. The course of the hot gases is directed (Fig. 71) lengthwise of the tubes in each bank by fire-brick baffles.

88. The Bigelow-Hornsby boiler has both vertical and inclined tubes. This boiler (Fig. 72) is distinctly sectional in construction. It is assembled from units, each of which comprises a group of straight water-tubes with header-drums (Fig. 73) on each end. The units are arranged in sections of four each (Fig. 72) longitudinally through the setting. The two rear units in each section stand vertically, while the two

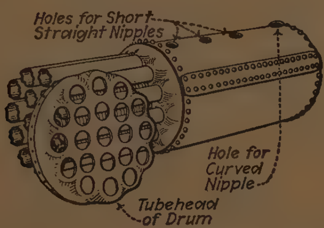


Fig. 73.—End of unit, showing construction of tube heads.

front ones pitch at an angle of about 65 deg. The capacity of a boiler of this construction is determined by the number of sections which it contains. The smallest boiler has three sections placed transversely in the setting. The largest has twelve. All of the units connect at the top to a horizontal main steam-drum (Fig. 74) which is 54 in. in diameter. It extends transversely across the setting.

89. The baffling in the Bigelow-Hornsby boiler (Figs. 75 and 76) is such that the flow of the furnace gases is transverse to the longitudinal axis of each tube-nest. Fig. 75 shows a cross-sectional view of the baffling in the first and second gas passes, counting from the front. Fig. 76 exhibits that in the third and fourth gas passes. Flat fire-clay tiles are used. Each baffle closes the space between the adjacent nests of tubes for the entire length from top to bottom.

90. Vertical water-tube boilers may, in general, be classified into two constructional groups. *First,* those which employ vertical tubes curved at one or both ends, either for junction with the head of a vertical steam-drum above and the shell of a central water-leg below, or with horizontal drums above and below (Fig. 77). *Second,* those which use straight

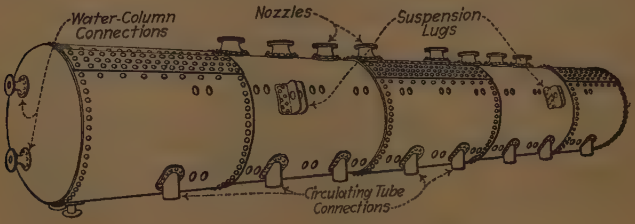


FIG. 74.—Main steam drum designed for a 10-section Bigelow-Hornsby water-tube boiler.

tubes (Fig. 78) connected into vertical drums at top and bottom.

91. The Erie City boiler is a typical example of the bent-tube design. In this (Fig. 77), two horizontal drums are set in the same vertical plane, crosswise of the setting. They are joined by three banks of tubes. The tubes in the two outer banks have their ends curved so that they enter the drums radially.

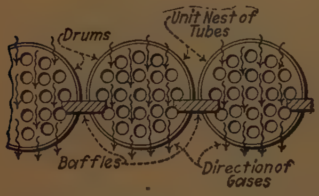


FIG. 75.—Baffling between units in first and second gas passes of B.-H. water-tube boiler.

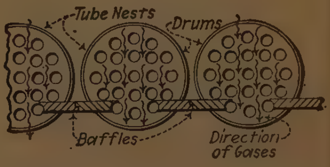


FIG. 76.—Baffling between units in third and fourth gas passes of B.-H. water-tube boiler.

The ends of the tubes in the middle bank are practically straight. Both ends of the upper drum rest in saddles, which are bolted to girders supported on a heavy structural-steel frame. The lower drum hangs suspended on the tube ends.

92. The baffling and course of the flue gases in the Erie city boiler is shown in Fig. 77. The gas flow is directed mainly

by baffles built against the rearward row of tubes in the front and middle banks. Three sets of short cross-baffles, inserted one above the other between the back wall of the setting and the rear bank of tubes, restrict the gases to a direct upward course among these tubes. The lower drum carries the weight

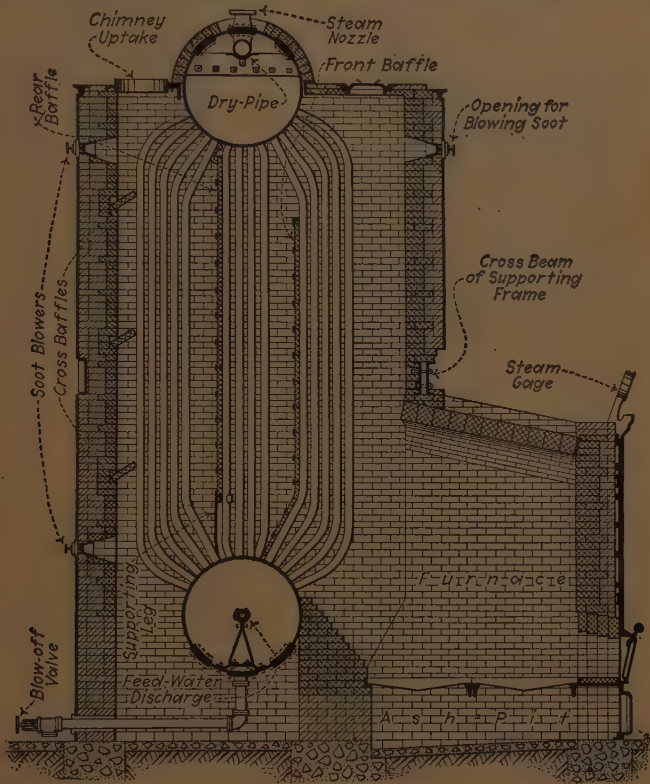


FIG. 77.—Sectional view of Erie City boiler and furnace.

of both the front and rear baffle walls. Supporting legs are inserted under the rear baffle to provide the necessary opening for the gases.

93. The Bass vertical water-tube boiler (Fig. 78) is one in which all of the principal structural elements are straight and vertical. Two cylindrical drums standing vertically one above the other, with a nest of straight tubes connecting

them, comprise the essential components of this boiler. Capacity requirements determine the lengths and diameters of the upper or steam drum, the lower or mud-drum and the dimensions of the tubes. The tubes are arranged in parallel

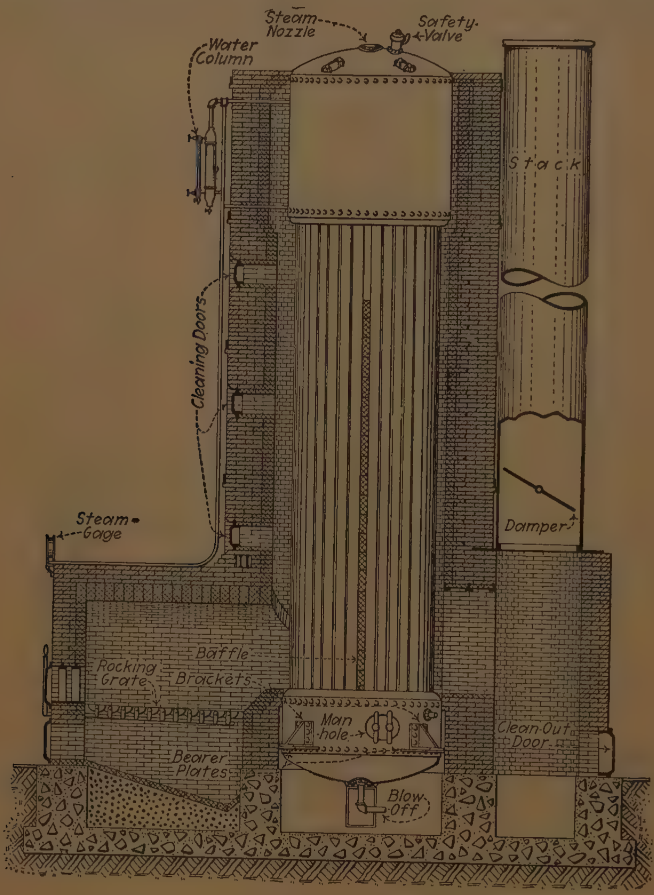


FIG. 78.—Bass vertical water-tube boiler.

rows from the furnace to the stack. There are clear spaces, sufficiently wide for cleaning out deposits of soot, between the rows. For supporting the boiler on the masonary foundation, four heavy pressed-steel brackets are riveted to the shell of the mud-drum at equidistant points. These brackets

rest on either a single cast-iron ring or on four heavy steel corner-plates which are embedded in cement in the masonry. Thus, the boiler stands independent of support from the surrounding brick-work. A fire-brick baffle-wall arranged transversely through the center divides the nest of tubes into two compartments. Thereby the hot gases are made to traverse the tubes lengthwise.

94. Porcupine boilers are vertical boilers designed on the principle of a multitude of pocket-tubes projecting from a central water-chamber. *The Hazelton boiler* (Fig. 79) is a typical example. While boilers of this type have in recent years been superseded by boilers of other designs, they were, about thirty years ago, installed frequently. A number are still in operation. Their main defect is imperfect circulation in the tubes.

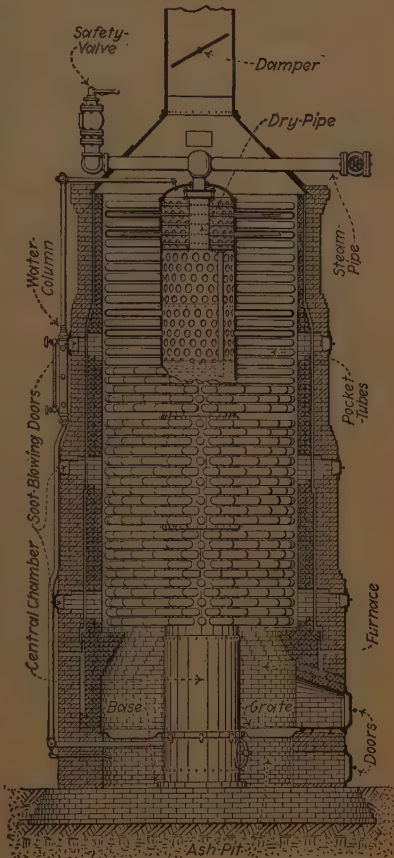


FIG. 79.—The Hazelton or Porcupine boiler.

95. The loop-tube boiler was designed to correct the principal defect in boilers of the porcupine type, by connecting both ends of each tube to the core shell. *The Morrin vertical boiler* (Figs. 80 and 81) is a typical example.

96. The Harrison boiler (Fig. 59) is a sectional boiler made with spherical steam chambers. These (Figs. 59 and 82) consist of an aggregation of spheroids, each about 8 in. in diameter. These boilers are no longer manufactured.

97. Boilers that combine both the fire-tube and water-tube principles in their design have been produced in several different forms. The Lyons boiler (Fig. 83) consists of two main sections: A cylindrical shell with its contained fire tubes and a pair of attached water legs connected together by a single transverse row of water tubes. The underlying idea in the development of this boiler was to improve circulation.

NOTE.—The rear water leg is 12 in. deeper than the one in front. Thereby the tubes are given a 5-deg. inclination downward to the rear. Access to the water tubes is through handholes of the customary style in

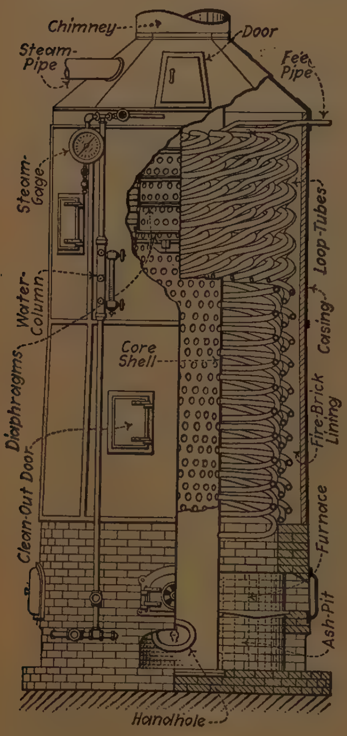


FIG. 80.—The Morrin-climax loop-tube boiler.

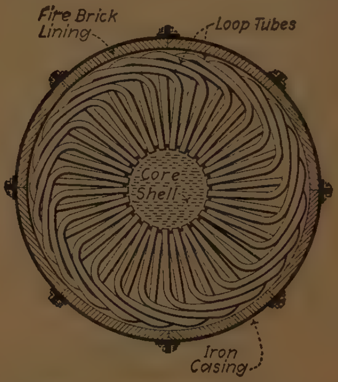


FIG. 81.—Cross section of Morrin boiler, showing method of looping the tubes.

the water legs. Fire-brick tiles are suspended from the water tubes back to a point just over the rear face of the bridge-wall. Fig. 84 illustrates the method of suspension. On top of the water tubes is an air-tight covering of clay tiles and cement. The boiler is supported independently of the setting by four cast-iron columns of the pattern shown in Fig. 85. A column is located at each corner—one under each end of the front and rear water legs. The legs bear directly on cast-iron plates (Fig. 85) which are free to travel on ball rollers.

98. The Page-Burton water-tube boiler (Fig. 86) consists of twin banks of straight tubes inclined at opposite angles

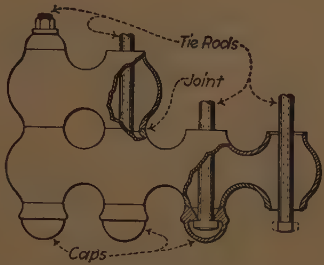


FIG. 82.—Two clusters of spheroids, showing mode of fastening.

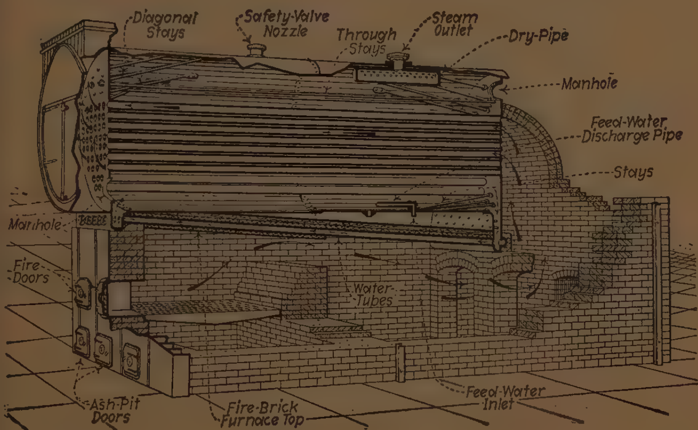


FIG. 83.—Longitudinal section of Lyons combination boiler with setting.

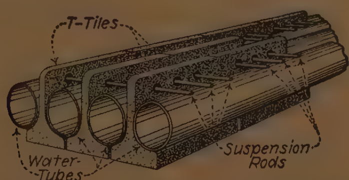


FIG. 84.—Method of suspending tube tile in furnace of Lyons boiler.

of about 18 deg. to the horizontal. They cross one another under a transverse steam-and-water drum to which they

are connected by curved tubes. The tubes in the twin banks are arranged in straight vertical rows. The tubes are expanded at each end into steel headers. Opposite each expanded tube-end is an oval handhole. It is closed by an inside plate with an outside bolt and yoke. The headers at the lower end of each bank connect to mud-drums. The mud-drums rest on fire-brick-lined piers of masonry. An air-tight casing, lined with asbestos cement, encloses the superstructure.

FIG. 85.—Supporting column for rear water-leg.

99. The cost of boilers is determined principally by the type, capacity, and the market price of raw materials. In general, the following prices represent fair values for the year 1919: Water-tube boilers of average size and pressure, approximate cost, f.o.b. factory, \$15.00 to \$20.00 per horse power; installed, \$25.00 to \$40.00 per horse power. Horizontal-return tubular boilers, f.o.b. factory, cost approximately \$14.00 to \$18.00 per horse power; installed, \$19.00 to \$23.00 per horse power.

QUESTIONS ON DIVISION 3

1. In what form of boiler in present use, is the simplicity of the primitive forms preserved?
2. What are average dimensions for plain-cylinder boilers?
3. What is a battery of boilers?
4. Describe a double-cylinder boiler.
5. What advantage was the double-cylinder boiler designed to secure?
6. Describe the method of boiler-suspension with equalizing levers.
7. What benefit do the equalizers secure?
8. Describe the elephant boiler.
9. What is the fundamental difference between internally-fired and externally-fired boilers?
10. What is a boiler "flue?"
11. What is a boiler "tube?"
12. What distinguishes the return-tubular boiler from the return-flue boiler?
13. The length and total cross-sectional area of the tubes being the same, which will have the greater area of tube heating surface—a multitubular boiler with 3-in. tubes or one with 2.5-in. tubes?
14. What is the average plate-thickness in the shells of return-tubular boilers? In the heads?

15. What is the usual ratio of steam space to total shell space in return-tubular boilers? Figured on this basis, how many cubic feet of water would a boiler of 48-in. diameter, 14-ft. length and filled with forty-six 3-in. tubes ordinarily contain?

16. What is the chief objection to bracket-support of a shell boiler?

17. Wherein does the performance of the return-flue boiler excel that of the return-tubular boiler?

18. Wherein do return-tubes show superiority over return flues?

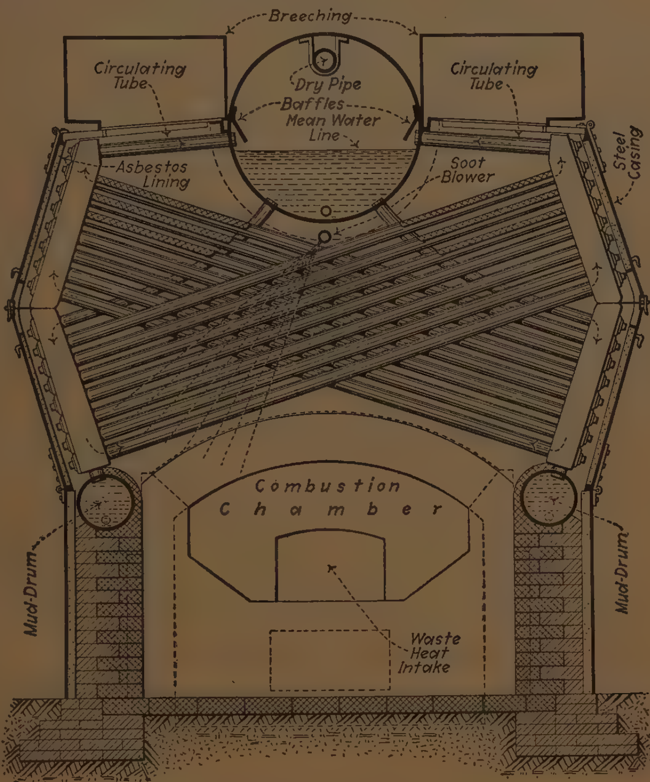


Fig. 86.—Page-Burton water-tube boiler set for using waste heat.

19. Is the general design of the return-tubular boiler conductive to smokeless combustion of bituminous coals? Why?

20. What considerations, in any case, might decide the choice of a boiler type in favor of the return-tubular boiler?

21. When is a boiler said to be self-contained?

22. What is a double-Cornish boiler?

23. How do Galloway tubes improve the performance of a Lancashire boiler?

24. Give a brief description of the Scotch boiler?

25. What is the outstanding advantage of the Scotch boiler? What is its principal defect?

26. What is understood by the terms "dry-back" and "wet-back"?

27. Give a brief description of the locomotive type of boiler used in portable and stationary plants.

28. Mention the principal merits and demerits of boilers of the locomotive fire-box and related types.

29. Why is the submerged-tube make of vertical fire-box boiler more apt to deliver wet steam than is the boiler of this type with exposed tubes?

30. For what purposes is the vertical fire-tube boiler particularly well-adapted?

31. What benefits does the double-diameter shell of the Manning boiler secure? What is gained by lengthening the tubes?

32. Define a sectional boiler.

33. Which of the boilers so far described and illustrated in this book may be regarded as truly sectional? Which as quasi-sectional?

34. Will a sectional boiler of a given capacity weigh more or less than a non-sectional boiler of the same capacity?

35. Whereon rests the claim of safety for sectional boilers?

36. Why is rapidity of water-circulation especially desirable in sectional boilers?

37. Give a brief general description of the Babcock & Wilcox boiler.

38. With what structural arrangement in the Babcock & Wilcox boiler are elliptical handholes used? Circular handholes?

39. What devices are used for directing the products of combustion to proper contact with the heating surface of a Babcock & Wilcox boiler?

40. Give a brief general description of the Heine boiler.

41. Describe the "water-legs" of the Heine boiler.

42. Describe the handholes in the Heine boiler.

43. How are the baffles arranged in a Heine boiler? To what direction of travel, relative to the tube lengths, are the products of combustion mainly constrained by this form of baffling?

44. Give four examples of vertically-inclined water-tube boilers.

45. Give a brief description of the Stirling boiler. Of the Bigelow-Hornsby boiler.

46. How is the sectional principle manifested in the Stirling boiler? In the Bigelow-Hornsby boiler?

47. How do the products of combustion traverse the tubes of a Stirling boiler? Of a Bigelow-Hornsby boiler?

48. What forms of tubes are found in vertical water-tube boilers with horizontal drums? In boilers with vertical drums?

49. How are the furnace gases baffled in an Erie City boiler?

50. Give a brief description of the Bass water-tube boiler.

51. Do porcupine and loop-tube boilers exhibit the sectional principle in like degree with standard makes of water-tube boilers?

52. What structural principle of the haystack boiler is conspicuously exemplified in the Harrison boiler?

53. Give a brief description of the Page-Burton boiler.

DIVISION 4

BOILER CODES AND INSPECTION LAWS

100. Boiler codes which specify the properties of the materials which should be used in, and the detailed construction of steam boilers have been in force in different parts of the world for many years. When steam boilers first came into extensive use, there were many disastrous explosions. These were due to ignorance and to faulty design and construction. The boiler codes were formulated and adopted by different countries, states, and cities to minimize the loss of life and property due to these explosions.

101. The American-Society-Of-Mechanical-Engineers' Boiler Code is, apparently, destined to supersede all others in the United States insofar as stationary power-plant boilers are concerned. It is probably the most comprehensive, logical, and rigid code for the construction of stationary boilers that has ever been compiled. The boiler code legalized by the state of Massachusetts was the first complete and exhaustive one which had statutory force. Prior to the formulation of the A.S.M.E. Code, this Massachusetts Code was adopted practically intact by a number of states and cities. However, the A.S.M.E. Code, which was accepted by the council of that body on Feb. 13, 1915, has, in recent years, been adopted widely.

Note.—To date—February, 1920—the following (See Fig. 87) have adopted the A. S. M. E. Boiler Code:

States.—Massachusetts, New York, New Jersey, Pennsylvania, Delaware, Michigan, California, Missouri, Rhode Island, Wisconsin, Minnesota, Ohio, Indiana, Oklahoma and Oregon.

Counties.—Allegheny, Penna.

Cities.—Detroit, Mich; Erie, Penna.; Kansas City, Mo.; St. Louis, Mo.; Philadelphia, Penna.; St. Joseph, Mo.; Chicago, Ill.; Nashville, Tenn., and Memphis, Tenn.

The U. S. Government now specifies that boilers for many important departments are to be in accordance with the *A. S. M. E. Boiler Code.*

102. Boiler codes are in reality laws in the communities where they are in force. They specify definitely how boilers should be constructed. Their acceptance and inclusion in a statute by the legislature of a state, or their embodiment in an ordinance by a municipality gives them legal force. Hence, infringement of these codes is a violation of the law and is punishable as prescribed by the various ordinances or statutes.

103. The American-society-of-mechanical-engineers' boiler code includes specifications as to the chemical and physical properties of the various materials which are used in boiler construction, and directs how these materials shall

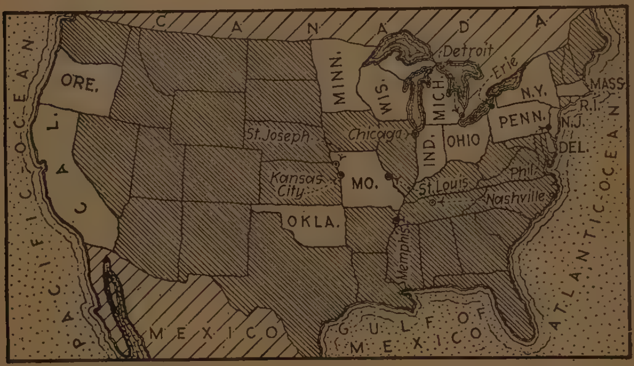


FIG. 87.—Map of United States showing in white the states that have adopted the A. S. M. E. boiler code.

be disposed in a finished boiler. (Further references to the A.S.M.E. Code will be found in succeeding divisions of this book on the subjects of STRESSES IN AND STRENGTHS OF STEAM BOILERS, RIVETED JOINTS, BRACES AND STAYS, etc. etc.) Tests—both chemical and physical—are outlined in the code whereby the fitness of the different metals for boiler construction may be determined. Factors of safety are given. The efficiencies of riveted joints are stated. The mounting of steam gages and other boiler accessories, and, in fact, every element which ordinarily affects the integrity of the complete boiler unit under the stresses of wear and tear of service is given consideration.

NOTE.—To obtain a copy of the A. S. M. E. Code, apply to the Secretary of the American Society of Mechanical Engineers, 29 W. 39th St., New York City. Send $1.00 if a non-member, and 50¢. if a member of the Society.

104. Whether or not the American-society-of-mechanical-engineers' rules apply to a boiler is determined by the statutes of the state, which should, in every case, be consulted. Ordinarily boilers which operate at pressures of less than 15 lb. per sq. in. are not subjected to code regulations. Furthermore, railroad locomotive boilers which are liable to inspection under federal laws, and small portable boilers, are usually exempt. Boilers on sea-going merchant vessels and on boats plying navigable rivers are constructed in accordance with the rules and regulations prescribed by the Board of Supervising Inspectors, Department of Commerce and Labor.

105. How the boiler codes and inspection laws operate may be explained thus: It is provided by each community which adopts a boiler code that the owners of all boilers operating therein must comply with the requirements of the code. Before a new boiler is fired, it must be accepted by an authorized state or municipal inspector as complying with the requirements of the code in force. After installation, boilers are examined periodically by the authorized inspectors. Such inspections are, ordinarily, made annually. In requesting quotations for a new boiler, it should be specified that it must conform to the requirements of the boiler code in force in the community where it is to be installed.

106. Inspection laws in various states and localities may or may not form part of the established boiler code. Wherever a code is adopted, it is obvious that inspections by competent experts must be made periodically to insure that the boilers operating there will be maintained within the margin of safety established by the boiler code. Every power plant operator should be conversant with the boiler code and inspection laws to which his plant is subjected, and he should have in his files for reference a copy of such.

NOTE.—THE METHOD ADOPTED BY THE A. S. M. E. BOILER CODE COMMITTEE FOR KEEPING IN TOUCH WITH THE WORK IN THE FIELD is this: Meetings of the committee are held monthly. At these meetings

action is taken on all inquiries regarding the Code or interpretations thereof. This service has been maintained gratuitously since the completion of the first edition of the Code.

QUESTIONS ON DIVISION 4

1. What does a boiler code specify?
2. Why is a boiler code adopted by a state or city?
3. What boiler code seems to be destined to supersede all others? Why?
4. What was the first comprehensive boiler code which was given statutory force?
5. Is your state or city included in the list of communities now governed by the A.S.M.E. Boiler Code?
6. Has a boiler code legal force when included in an ordinance or statute?
7. What are some of the important subjects treated in the A.S.M.E. Boiler Code?
8. What boilers are ordinarily not effected by the A.S.M.E. Boiler Code?
9. In accordance with what body's ruling are boilers on sea-going merchant vessels and river boats constructed?
10. How do boiler codes and inspection laws operate?
11. What fundamental stipulation should govern in all negotiations for the purchase of new boilers?
12. Why is authoritative boiler-inspection necessary?
13. How does the A.S.M.E. Boiler Code Committee keep in touch with the work in the field?

DIVISION 5

MATERIALS USED IN STEAM BOILER CONSTRUCTION

107. The materials used in boiler making are the following: (1) *Wrought iron.* (2) *Mild or low-carbon steel* (see note below). (3) *Cast iron.* (4) *Cast steel.* (5) *Malleable iron.* (6) *Copper.* (7) *Bronze.* (8) *Brass.* This enumeration includes all of the metals that have been employed more or less extensively in the construction of boilers since the pioneer days of steam-power.

NOTE.—*Flange, fire-box, rivet, staybolt, bar* and *boiler-tube* are terms referring to different grades of mild steel which are specified in the A.S.M.E. CODE for boiler construction. *Wrought steel* is any steel that has been *worked* in the process of manufacture. The term is used in contrast to *cast steel.*

108. Quality of the materials used in steam-boiler construction demands critical attention for the following reason: In performing its function (Div. 1) a steam boiler is subjected continually to disruptive stresses. These are due to high internal pressures and to excessive changes in temperature. Disastrous consequences will inevitably follow if the material fails under these stresses.

NOTE.—The steam boiler is exposed to a greater variety of conditions which tend to effect its deterioration than is any other power-plant member. While a boiler is in service, the fibers of its material are subjected to constantly-varying molecular stresses due to the continually-changing temperatures. This inconstant stress tends to induce a change of molecular structure (crystallization) which diminishes insidiously the strength of the material. Furthermore, the material is subjected often to unnecessary torture and abuse because of accidental circumstances. These may be an excessive steam pressure, or a deficiency of water.

109. The quality of the material in the different parts of a boiler should be selected with special reference to the stresses and disruptive influences which each part encounters in service. Certain portions of the structure must be particularly capable of withstanding pulling stresses. Still

others have shearing and crushing forces imposed upon them. One part must have a peculiar hardness to resist the wasting away of the material by erosion. Another must have superior toughness. Still another must be especially adapted to resist the attacks of corroding elements.

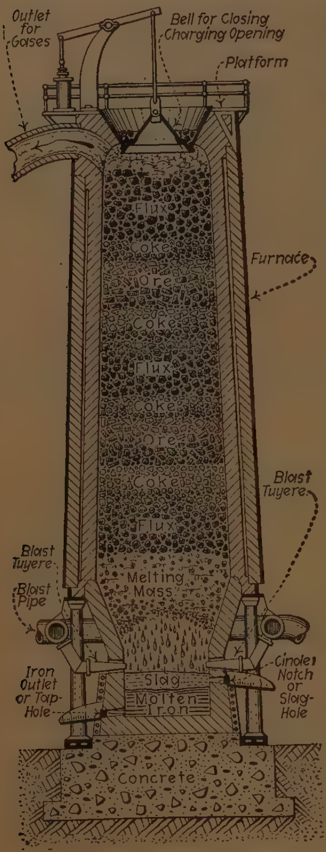


Fig. 88.—Blast furnace.

110. Charcoal iron is a high grade of wrought iron. It contains the highest percentage of pure iron of any of the commercial products evolved from the native ore. It may be used in steam boilers for tubes. It is manufactured from iron ore. There are two stages in the process. *First,* the charge of iron ore is smelted into pig iron in a blast furnace (Fig. 88). Wood-charcoal alone is used for fuel in making charcoal pig iron. (In making ordinary iron, coke is used). This wood-charcoal is practically free from the impurities which are present in coke and similar fuels and which would affect the purity of the product. *In the second stage* of the process, the pig iron is melted and rabbled in a puddling furnace (Fig. 89) with oxide of iron. The function of the puddling furnace (Fig. 89) is to remove the carbon from the pig iron. Usually the product of the puddling furnace contains not more than 0.5 per cent. (0.005) of impurities. The iron oxide is usually red oxide of iron or hematite ore. The carbon in the pig-iron charge is expelled by its union with oxygen. The two elements (the carbon from the pig iron and the oxygen from the oxide) combine to form carbon dioxide (CO_2) and

pass off as such. This converts the original brittle charge to the malleable state which is characteristic of wrought iron.

111. Wrought iron comes from a puddling furnace as a soft plastic ball saturated with slag. The ball is dropped into a machine (Fig. 90) which squeezes out most of the slag. The "shingled" mass of metal is then passed through a train of rolls (Fig. 91) which ejects much of the remaining slag. During this operation, the plastic mass solidifies into the form of a bar. This "muck-bar" is now cut into strips. A sufficient number of strips to produce a sheet of the desired size are bound into a bundle or pile (Fig. 92). After being brought to a welding heat, the pile is rolled out into a plate of the required thickness.

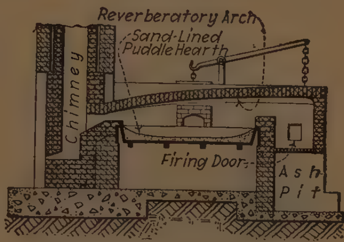


FIG. 89.—Longitudinal sectional elevation of puddling furnace.

112. A wrought iron plate consists of a series of welds (Fig. 93). This is evidenced by its laminar structure. Its fibrous texture is due mostly to the presence of slag in the material. The rolls draw the metal out into a stringy mass. Each fiber of iron is the core of a slender thread of slag.

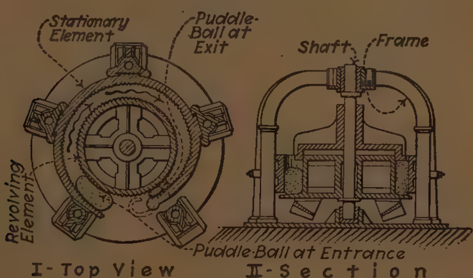


FIG. 90.—Rotary squeezer for squeezing out slag.

113. Mild or low carbon steel is an alloy of pure iron with small proportions of carbon in chemical combination as iron carbides and of other elements. It is manufactured from pig iron. The charge of iron is melted in a reverberatory furnace (Fig. 94). Sufficient oxide of iron is added to insure

the expulsion, in the furnace, of the carbon which was in the original charge. Then the quantity of combined carbon necessary to render the metal structurally adaptable is added subsequently. Mild steel made by the Bessemer process is not used for boiler plate.

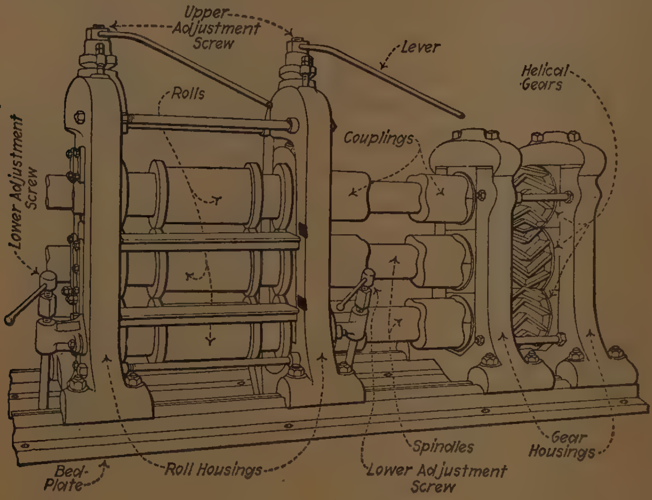


FIG. 91.—Train of rolls.

114. Mild steel for boilers is made by the open-hearth process (Fig. 95). In this process either of two methods—"*the basic method*" or the "*acid method*"—may be used.

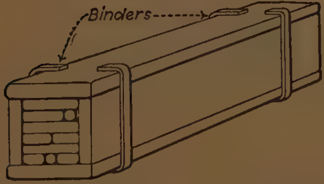


FIG. 92.—Pile of muck-bar strips and wrought iron scrap prepared for reheating.

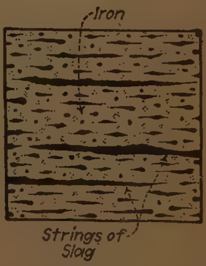


FIG. 93.—Showing lamina, in wrought iron, of slag and iron (magnified 50 diam.)

These terms refer to the chemical reactions which occur in the furnace. Refractory substances, of either an alkaline or an acid nature in the lining of the furnace and in the slag, are the

determining factors in the reactions. The slag is the semi-fluid which forms in the furnace from the mixing of the chemical impurities in the metal charge with the fluxing material which is used.

115. The acid is simpler than the basic method but it removes none of the phosphorous and sulphur from the charge of pig iron. The quantity of these impurities is, there-

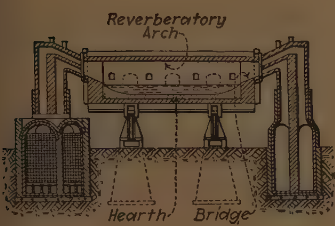


FIG. 94.

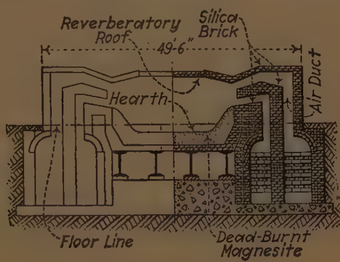


FIG. 95.

FIG. 94.—Reverberatory furnace for steel manufacture. (The furnace shown is carried on a track so that it can be moved longitudinally. In a reverberatory furnace the metal is exposed to the action of the flame, but is not in contact with the burning fuel. The flame passes over the bridge, strikes the roof of the furnace and then reverberates, or rebounds, downward on the metal which is spread on the hearth.

FIG. 95.—Sectional elevation of Basic open hearth furnace.

fore, greater in the product of the acid method. Hence, the basic method is preferred for the manufacture of mild steel. Mild steel comes from the furnace in a molten state and is cast into ingot molds. The ingots are then reheated and rolled into plates.

116. Mild steel is distinguishable from wrought iron only in its physical characteristics. Chemically, low-carbon steel—that is mild steel—and charcoal or other wrought iron are virtually the same. The principal difference between the two metals is a structural one. The mild steel is homogeneous, whereas the wrought iron is, due to the different method of its manufacture, laminated and of fibrous texture. Since mild steel has but a trace of combined carbon and other strengthening elements it is often called "ingot" iron. True or tool steels can be tempered; mild steel can not.

117. Wrought iron has been superseded as a material for boiler plates by mild steel within the last forty years. Mild

steel, made by the open-hearth process, is now the only material specified for shells, drums, and fire-boxes or any plates that require staying or flanging in boilers.

118. The suitability of manufactured iron or steel for boiler-making is determined by tests—some chemical, some physical. The standard tests are specified in detail in the A.S.M.E. Boiler Code. A chemical test or analysis determines the relative proportions of the various component chemical elements which are enumerated in the following Sec. These elements are usually inseparable from the finished product. Excepting carbon, without which iron would be of little or no commercial value, these elements are present in mild steel, principally because it would be prohibitively expensive to eliminate them. A physical test reveals the effects of these elements upon the general strength and durability of the material.

119. The principal elements besides pure iron which compose mild steel, as it is used for boiler-making are: (1) *Carbon.* (2) *Phosphorous.* (3) *Sulphur.* (4) *Silicon.* (5) *Manganese.*

120. Table.—Essential Physical Properties of Materials for Boiler-making.

Quality	Definition	Criteria	Example
Tenacity.......	Ability to resist a pulling stress.	Ultimate tensile strength as determined by tension test.	Resistance of through stays.
Elasticity......	Capacity for resuming normal shape after deformation.	Extent of deformation from which specimen will completely recover.	Action of spring-tubes in pressure gages.
Hardness......	Ability to resist erosion or wear.	Behavior of specimen in abrasion test, scratch test, or ball test.	Imperviousness of good fire-box steel to cutting action of cinders.

Quality	Definition	Criteria	Example
Ductility......	Ability to endure elongation without fracture or rupture.	Degree of elongation of specimen in tension test.	Stretching of stay-bolts or plates in tension.
Malleability....	Ability to endure change of shape by hammering, bending, or rolling.	Behavior of specimen in bending test.	Flow of rivet material under blows of hammer or pressure of riveting machine.
Toughness.....	Ability to endure continued torture by twisting and bending—absence of brittleness.	Behavior of specimen in torsion test.	Resistance of boiler-plate to an alternating flexure in riveted seams.
Resilience......	Capacity for storage of returnable work energy as the material is strained to the elastic limit.	Modulus of resilience as determined by tension test.	Action of steel spring under tension or compression.
Homogeneity...	Continuity and uniformity in the grain or fiber of the material.	Appearance of fractured surfaces of broken specimen.	Condition of a soft steel rivet after being driven under 80 tons pressure while at a reddish white heat.

121. **An essential property of boiler-plate is a uniform blending of the physical properties** that will enable the material to recover from the strains induced by the various stresses of operation.

122. **The most important property of boiler-plate is tenacity** or tensile strength. Carbon is the ingredient which enhances this property. Carbon possesses no great strength on its own account, but when it is combined chemically with

iron, it then develops greater strength therein. However, to insure this, correct proportions must be maintained. Increasing the carbon content up to a certain maximum augments the strength. But beyond this maximum, the strength decreases with the increase of carbon content.

EXAMPLE.—Mild steel that contains 0.1 per cent. of carbon has a tensile strength of about 50,000 lb. per sq. in. With twelve times this quantity or 1.2 per cent. of carbon, the tenacity, if tempered, is increased to nearly 140,000 lb. per sq. in., which is probably the upper limit for carbon steel. Increasing the percentage of carbon above this value results in a proportionate drop in the tenacity. With 2.0 per cent. its unit strength is about 90,000 lb. Further gradual increase in the carbon component causes the material to become brittle.

123. Carbon contributes to the hardness of boiler-plate. The hardness increases with the increase of carbon content. This quality is especially desirable in flues and tubes and in the sheets of fire-boxes and combustion chambers. In these locations the metal must withstand the abrading action of the cinder-laden gas currents. There is, however, a degree of hardness which marks the maximum limit. If an attempt is made to obtain harder metal, other very necessary qualities of good boiler-plate will be sacrificed.

124. Excessive carbon tends to destroy ductility of the material. Its malleability may also be thereby impaired to a ruinous extent. Likewise, a plate containing an excess of carbon will be lacking in toughness. Sufficient carbon to make the plate quite hard will also make it brittle.

125. Good boiler-plate steel contains just enough carbon to insure proper melting in the furnace. This consideration amply gages the amount of carbon necessary to produce a satisfactory blending of the desired properties. Generally, the quantity of carbon is less than 0.25 per cent. With this small carbon content, practically all liability of the material to harden and crack under a stress, which is caused by a sudden and wide change of temperature, is eliminated.

126. Phosphorus is undesirable in boiler-plate steel.— Although its presence makes a steel strong and hard, and thus would seem desirable, these qualities are secured best through the medium of carbon. The reason is that phosphorus tends

to make the material cold-short, that is brittle, when cold. Steel containing much phosphorous is particularly weak against shock and vibratory stresses. On this account, it may be considered the most harmful of the ingredients in steel boiler-plate. It is for this reason that Bessemer process steels are undesirable for boiler-making. The method does not remove from the steel the phosphorus, which was originally in the pig iron.

127. Sulphur is detrimental to steel in various ways. Its principal effect is to impair the tenacity and ductility of the plate and to make it hot-short, or brittle and difficult to work when hot.

128. Silicon In Mild Steel Makes It Harder.—There is but a small quantity present. Even this increases the hardness slightly, but without diminishing toughness or ductility and without affecting appreciably its tensile strength. This might, therefore, be regarded as a beneficial ingredient.

129. Manganese In Mild Steel Is A Hardening Agent.—Steel which contains a considerable proportion of this element acquires a peculiar brittleness and hardness which makes it difficult to cut with machine tools. Manganese has, however, a neutralizing effect on sulphur. It combines with sulphur in the steel to form manganese sulphide. This component is less objectionable than the iron sulphide that would otherwise be formed. The presence of manganese might, therefore, be regarded as advantageous.

130. Chemical Properties For Steels Are Specified By The Boiler Codes.—The standard rules, those of the *American Society of Mechanical Engineers* for example, stipulate certain chemical properties for steels of various grades for plates, stays, rivets, and the like. (Table 131.)

131. Table Showing the Uses, Chemical Properties and Physical Properties of the Various Grades of Steel and Iron as Specified in the A.S.M.E. Code, 1918.

	Material		Where used	Chemical properties: Carbon, per cent.	Chemical properties: Manganese, per cent.	Chemical properties: Phosphorus maximum per cent.
Steel	Firebox (plate)		Parts exposed to fire and under pressure. Also other plate.	Less than $\frac{3}{4}$", 0.12–0.25. Over $\frac{3}{4}$", 0.12–0.30	0.30–0.50	Acid, 0.04 Basic, 0.035
Steel	Flange (plate)		For parts when firebox quality is not specified. Manhole and handhole covers.		0.30–0.60	Acid, 0.05 Basic, 0.04
Steel	Rivet		Rivets		0.30–0.50	0.04
Steel	Staybolt		Staybolts		0.30–0.50	0.04
Steel	Bars		Braces, and other bars not otherwise specified			Acid, 0.06 Basic, 0.04
Steel	Tube, lapwelded and seamless boiler		Lapwelded tubes and all seamless tubes	0.08–0.18	0.30–0.60	0.04
Steel	Castings	Class A	Water-leg and door-frame rings.	0.30 Max.		0.06
Steel	Castings	Class B: Hard	Cross pipes, headers, cross-boxes, and pressure parts over 2 in. pipe size. Mud-drums Parts of superheaters. Water-leg and door-frame legs.			0.05
Steel	Castings	Class B: Medium				
Steel	Castings	Class B: Soft				
Iron	Rivet		Rivets			
Iron	Staybolt		Staybolts			
Iron	Refined wrought-bars		Braces when welded			
Iron	Charcoal iron		Lapwelded tubes			
Iron	Malleable castings		Cross pipes, headers, cross-boxes when pressure is less than 200 lb. per sq. in. and section within 7 in. × 7 in.			0.225
Iron	Gray castings	Light	Boiler and superheater mountings, pipes, fittings, valves for temperature less than 450 deg. Fahr. Headers in water-tube boilers.	(Any section less than $\frac{1}{2}$" thick).		
Iron	Gray castings	Medium		(Castings not included in "Light" and "Heavy")		
Iron	Gray castings	Heavy		(No section less than 2" thick).		

	Physical property					
ulphur, aximum, er cent	Tensile strength, lb. per sq. in.	Yield point, lb. per sq. in.	Elongation, per cent. in 8 in. at least	Elongation, per cent. in 2 in.	Reduction area, minimum per cent.	Special tests
0.04	55,000–65,000	0.5 tensile strength	$\frac{1,500,000}{\text{Ten. Str.}}$ Min. = 20%			Bend homogeneity
0.05	55,000–65,000					Bend
0.045	45,000–55,000		$\frac{1,500,000}{\text{Ten. Str.}}$			Bend, quench and cold.
0.045	50,000–60,000		Max. = 30%			Flattening
0.05	55,000–65,000		$\frac{1,500,000}{\text{Ten. Str.}}$ Min. = 18%	22 min.		Bend
0.045						Flange Flattening Hydrostatic
0.05	80,000	36,000		15	20	Bend Destruction
	70,000	31,500		18	25	
	60,000	27,000		22	30	
	48,000–52,000	0.5 tensile strength	28		45	Bend, cold, hot, and nick. Etch.
	49,000–53,000		30		48	Bend, cold, quench and nick. Etch.
	45,000–53,000	25,000	22 to 16 min.			Bend, cold hot, and nick. Etch.
						Flange Flattening Hydrostatic
0.06	40,000					Transverse
0.08	18,000					Transverse
0.10	21,000					
0.12	24,000					

132. Steel which is to be used in boiler manufacture should, steel castings excepted, be made by the open-hearth process. Castings may be open-hearth, crucible or other process steel which affords a good product. Steel plates for any part of a boiler, when exposed to the fire or products of combustion and under pressure, should be of fire-box quality. For any part under pressure, where firebox steel is not required, the plate may be firebox or flange quality. Manholes and hand-holes covers, and other parts subjected to pressure, and braces and lugs may, when steel is used, be made of either firebox or flange quality. Steel bars used for braces should be of steel bar stock. Staybolts should be of either iron or steel stay-bolt stock.

133. The effect of high temperature on the tensile strength of steel was (*Power*, June 10, 1919, p. 910) investigated in 1880 by Dr. Huston of the Franklin Institute. His experiments show that up to 700 deg. fahr. the tensile strength was equal to 100 per cent. of, or even better than the original. However, when the temperature was increased above 700 deg., the curve dropped sharply. That is, above 700 deg. the tensile strength decreases. Similar tests by other experimenters corroborate these data.

NOTE.—It appears safe to state that low-carbon steels of 50,000 to 60,000 lb. per sq. in. tensile strength will be thoroughly safe up to temperatures of 600 deg. fahr. The critical temperature of steel varies but little between hard, soft, and medium steels. Steels of tensile strengths greater than those above noted would not be desirable for the reason that as the critical point in steel—say about 700 deg. fahr.—is approached, the metal becomes less ductile and would be more likely to crack.

134. The physical tests for different classes of iron and steel comprise mainly, tests for: (1) *Tenacity;* (2) *Ductility;* (3) *Elasticity* (4) *Malleability*. Secondarily, they comprise tests for: (5) *Homegeneity* (6) *Ability to resist compression.*

135. The tension test consists in stretching the specimens in a testing machine (Figs. 96 and 97) until the specimen is pulled apart. The pull exerted, on the specimen, by the machine and indicated by it at the instant of rupture measures the ultimate tenacity, that is, the ultimate *tensile strength* of

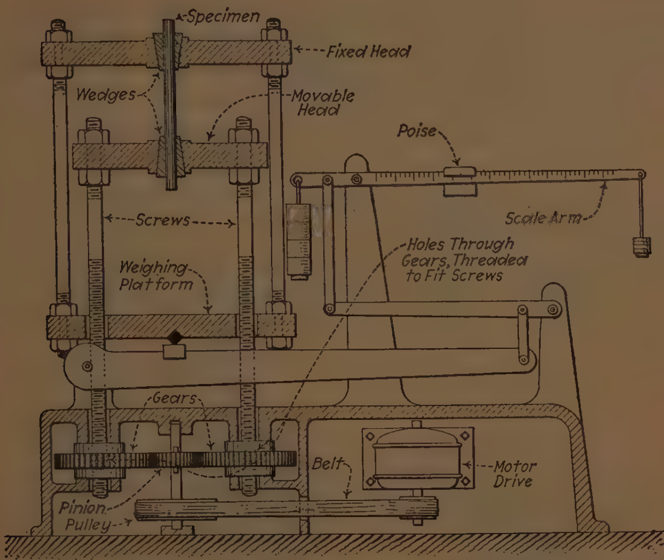


FIG. 96.—Diagram illustrating the principle of a standard tension and compression testing machine. (This is not intended to show actual construction.)

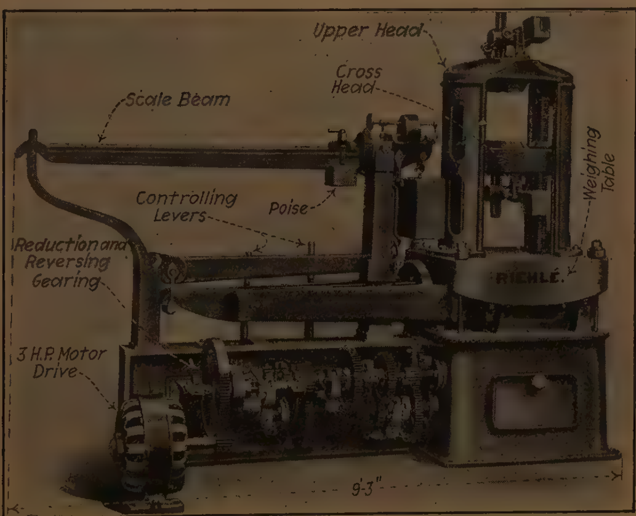


FIG. 97.—External appearance of a standard tension and compression testing machine (100,000 lb. or 50,000 kilogram capacity).

the material. During this test the elasticity and ductility of the steel may also be determined.

136. The method of conducting tension tests is as follows: The clamps (Fig. 98) of the extensometer are applied 9 in. apart on the specimen. The extensometer is an instrument for measuring elongation. It is made in numerous forms. The specimen with the extensometer on it is secured in the testing machine by clamping it in the wedge jaws (Figs. 99 and 100) with which every testing machine is equipped. Then the load is applied until the specimen is gripped. Now the distance between the index points of the extensometer

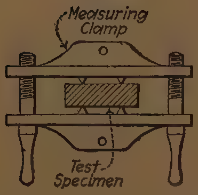


FIG. 98.—End view of plate (rectangular) test specimen showing measuring clamp applied.

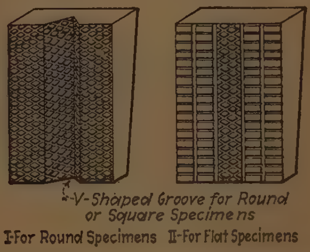


FIG. 99.—Forms of jaws or wedge grips for flat and round specimens.

clamps is measured with a micrometer (Fig. 101). Some extensometers have micrometers which form integral parts of the instrument. Extensometer measurements are observed periodically as the test proceeds.

137. In measuring the elongation (Fig. 101) the micrometer is placed against a point on the flange of the clamp on one end. Then the length of the micrometer is so adjusted that it will just touch the corresponding point on the other clamp. As the load on the specimen is increased, the specimen stretches. The augmentation (Fig. 102) is, within the elastic limit, proportional to the increase in the load. The load which imposes the tension is continually increased, by the motor, or belt drive, which operates the testing machine, until the specimen finally breaks. The pounds load, imposed at any instant on the specimen, may be read from the scale arm in precisely the

same way as the weight is ascertained from the beam of a platform scale in a grocery store. The "poise" is moved along the beam as the test progresses so that it always just counterbalances and indicates the load (tension) in pounds, then im-

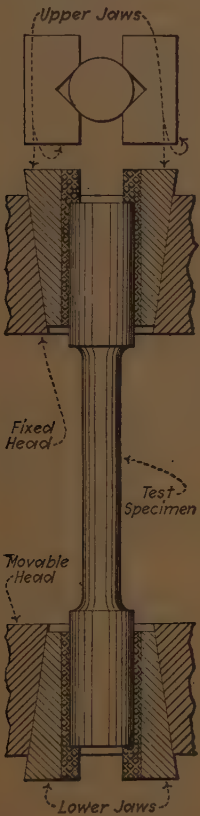


FIG. 100.—Showing arrangement of wedge shaped jaws of testing machine (Tinius Olsen Company).

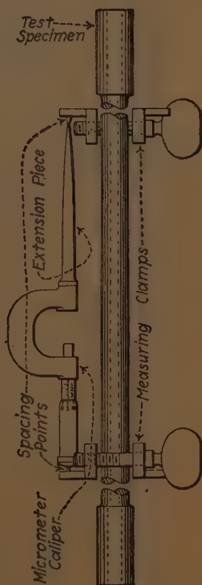


FIG. 101.—Edge view of round test specimen showing application of micrometer caliper.

posed on the test specimen. Thus the load in pounds at which the specimen breaks may be determined.

138. The elastic limit of the material is attained during the progress of the test. This is the limit (the load, in pounds per square inch) beyond which the material cannot be stressed

without producing a permanent change of shape. Precise determination of the elastic limit of a material demands extremely delicate adjustment and manipulation. Hence, in specifying boiler-steel it is the practice to base requirements on the yield point (see definition below) rather than on the elastic limit. The yield point, which can readily be determined, may be regarded as a sort of an approximate elastic limit. When a specimen is released from a tension less than its elastic limit, it will resume its original length.

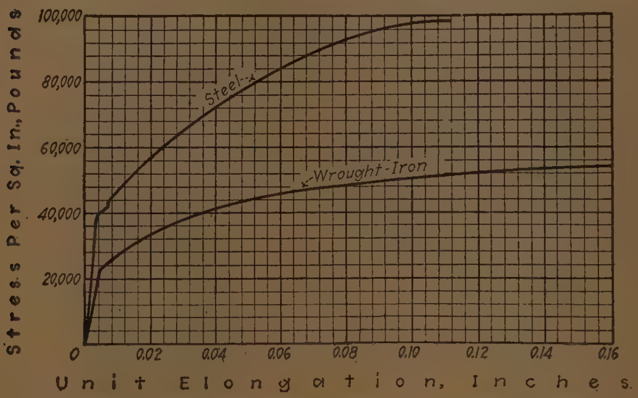


FIG. 102.—Typical stress diagram of tensile test of wrought iron and steel specimens.

139. The yield point is the stress under which the steel specimen begins to lengthen rapidly without a corresponding increase in the load. It is manifested by the scale poise on the testing machine indicating a diminished load (the testing machine beam drops) though the pull continues to be applied steadily. Thus, the specimen under test begins to draw down rapidly, somewhere near the middle of its length. Finally it breaks. The resulting fracture will have, usually, a cross-sectional area of about one-half to three-fourths of that which the original specimen had.

140. Jaws and wedges of a testing machine (Fig. 100) prevent stretching or flow of the material in the part of the specimen gripped by them. In fact, the clamping effect of the jaws may hamper the elongation of the material for a distance

of 2 or 3 in. beyond their edges. (The jaws of a machine having a capacity of from 50,000 to 100,000 lb. are 4 or 5 in. long.) The grip of the jaw (Fig. 99) will not be effective unless about 3 in. of the length of the standard specimen is seized at each end.

NOTE.—The test piece must have at least 8 in. of free length for measuring elongation. Also 2 or 3 in. must be allowed at each end for the flow of the material and from 3 to 5 in. must be provided for clamping, in the jaws. Thus it follows that the specimen must have an overall length of from 18 to 24 in. as shown in Fig. 103. The jaws have file-like flat faces (Fig. 99) for clamping flat specimens or V-notched faces for gripping round specimens (Fig. 104).

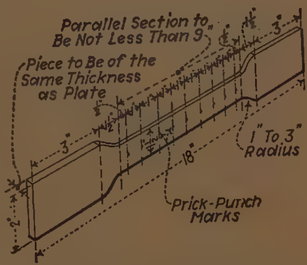


FIG. 103.—Steel-boiler-plate standard test specimen.

141. The tensile strength required for different grades of boiler steel as provided in the A.S.M.E. CODE is given in preceding Table 131.

142. Tension-test specimens (Fig. 103) of boiler plate are made from strips cut from the plates (Fig. 105) as they come from the rolls. The specimen is usually cut out (Fig. 105–*I*) in the direction of the longitudinal axis of the ingot from which the plate was rolled. But where the plate is to be so used

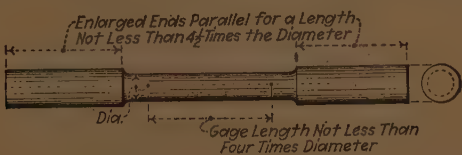


FIG. 104.—Standard test piece for round material.

that its transverse axis will lie in the circumference of the boiler-shell, the test specimen is then cut out (Fig. 105–*II*) at right angles to the axis of the ingot from which the plate was rolled.

NOTE.—The edges of each test specimen are milled down to a uniform cross-sectional area of not less than ½ sq. in. for a space of about 9 in. in the middle of the overall length of the specimen, which is about 18 in. This space is marked off as delineated in Fig. 103.

143. The resilience of a material is its capacity to return the work which has been imparted to it. It is measured in foot-pounds. It is, practically speaking, equivalent to the potential energy stored up in the strained specimen. The amount of resilience is, practically speaking, equal to the work—foot-pounds—required to deform the specimen, below the elastic limit, from zero stress to some specified stress.

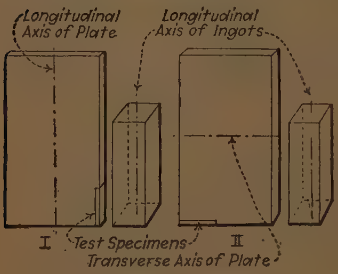


FIG. 105.—Showing location, in plate, of tension test specimens.

144. The modulus of resilience, or unit resilience, is the elastic energy stored up in a cubic inch of strained material at the elastic limit. It is (practically considered) the work done on a unit volume (one cubic inch) in stressing it to the elastic limit. It is, therefore, equal to half the product of the elastic-limit strength multiplied by the corresponding unit deformation.

EXAMPLE.—India rubber is very elastic because it will endure great deformation and yet return to its original form. But it is not very resilient because it has not, relatively, great capacity for resisting work. Steel is very resilient and quite elastic also. Steel will, within its elastic limit, endure deformation and yet return to its original form; hence it is elastic. It is very resilient because it requires much work to deform it, which work the steel—a spring for example—will give back if the force deforming it is released.

145. The ductility of the material is determined by the elongation of the specimen at the instant of failure. A material which can be stressed far beyond the elastic limit, undergoing during this stressing a considerable permanent deformation, is said to be "ductile." When the tensile stress exceeds the elastic limit the specimen becomes permanently lengthened. If it is of very ductile steel, it may stretch to 1.3 times its original length before breaking.

146. Compressive, or crushing, stresses in the section of metal between the edge of the sheet and the rivet holes must be considered in designing boiler seams. The molecules of

the metal oppose greater resistance to compression than to tension. Mild steel has a compressive strength of about 95,000 lb. per sq. in. The compression tests are effected with the same machine (Fig. 96 and 97) that is used for tension tests.

NOTE.—IN MAKING THE COMPRESSION TEST, the specimen is placed between the two plates or platforms of the machine, which are forced together by the turning of the powerful screws at each side which are driven by power. Fig. 106 illustrates the arrangement. In Fig. 107 is shown the typical result of a compression test on a mild steel specimen. The graph of Fig. 108 illustrates the typical performance of a specimen undergoing a compressive test.

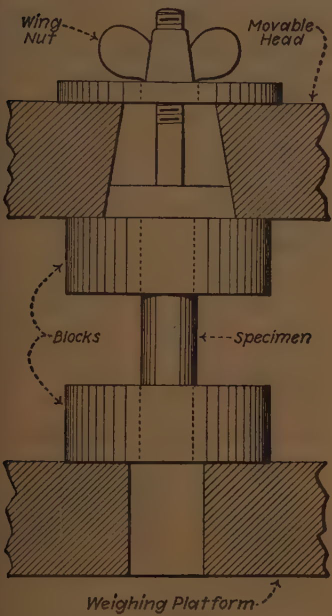


FIG. 106.—Arrangement of parts in compression test.

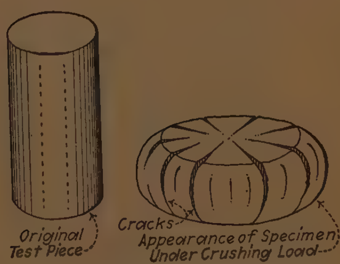


FIG. 107.—Steel specimen crushed in compression test.

147. Malleability is a prime requisite of good rivet steel. The comparatively low percentage of carbon in steel of this class insures malleability. But it also reduces the ability of the metal to resist shear and tension. Tension in the rivets of a boiler is, however, relatively unimportant. Furthermore, the cross-sectional area of rivets can, readily, be made sufficiently large to provide ample strength against shear.

148. The shearing strength of rivet steel is required (by the A.S.M.E. CODE) to be at least 44,000 lb. per sq. in. in single

shear (Fig. 109). In double shear, or where cut through simultaneously in two separate planes of cross-section (Fig. 109), it must be at least 88,000 lb. per sq. in. Specimens for the shearing tests are made as illustrated in Fig. 109. The plates which hold the rivets to be tested, those in Fig. 109, should have an area of cross-section sufficiently great that they will resist permanent distortion under any pulling stress less than the shearing strength of the rivet. The pounds tension under which the body of the rivet is cut or sheared through, is its ultimate shearing strength.

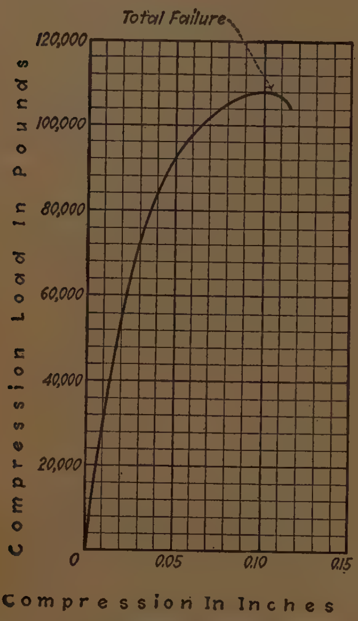


FIG. 108.—Typical stress curve of compression test.

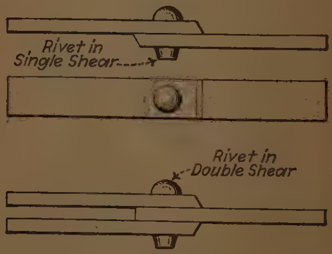


FIG. 109.—Specimens prepared for shearing tests.

149. The physical tests for boiler plate steel are: (1) *Tension* (Table 131). (2) *Bend test.* (3) *Homogeneity test,* applied only to fire-box steel. The preceding Table 120 and the following sections recite the most important details concerning these tests and properties.

150. Test Specimens should be taken from the finished rolled material (Fig. 105). The longitudinal-test specimen should be taken from the bottom of the plate (Fig. 105–*I*). The transverse-test specimen should be taken perpendicular to the fiber and form the bottom of the plate (Fig.105–*II*). The bend-test specimen should be taken from top and middle of the finished rolled material (Fig. 110). This latter requirement

is based on the assumption that any possible segregation of the hardened elements would tend to accumulate at the top of the ingot. Therefore, if a specimen, taken from the location noted, satisfies the prescribed test, it is reasonably certain that all other portions of the plate conform to the required standard.

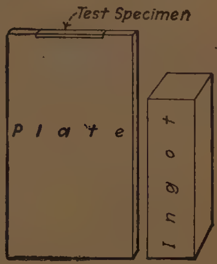


FIG. 110.—Showing location, in plate, of bend test specimen.

151. The bend test for boiler plate is as follows: For steel plate 1 in. or less in thickness, the specimen should bend cold (Fig. 111) 180 deg. without cracking, around a pin of diameter equal to the thickness of the plate; for plate over 1 in. thick, the diameter of the pin should be twice the thickness of the plate.

152. The test for homogeneity of fire-box steel should be made on a sample taken from a broken tension-test specimen.

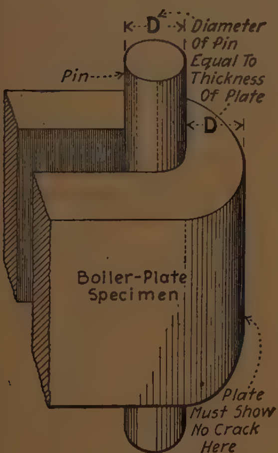


FIG. 111.

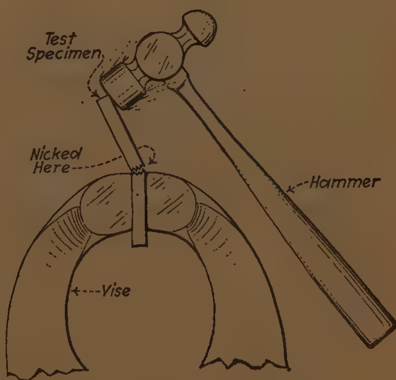


FIG. 112.

FIG. 111.—Bending test for materials thinner than one inch.

FIG. 112.—How specimen is broken for homogeneity test.

When the piece is nicked about 1/16 in. in three different places (see A. S. M. E. CODE) and broken (Fig. 112) the fracture

should not show any single seam or cavity more than ¼ in. long.

NOTE.—SMALL CAVITIES ARE LIABLE TO BE FORMED BY GAS BUBBLES in the molten ingot in the making of mild steel. Seams may also be found in the finished product. These may be due either to incomplete welding of separate strata of the metal, or to slag penetrating between the strata. These defects are particularly objectionable in steel which is intended for shells, drums, and butt-straps. The tensile stresses in these parts, and in stayed flat sheets as well, demand that the steel be as nearly homogeneous as it is practicable to make it. A lesser degree of homogeneity may be permitted in rivet steel. Of recent years, the processes of steel manufacture have been so perfected that little or no difficulty, due to these causes, is experienced.

153. Physical tests for rivet, staybolt and bar steels are: (1) *Tension test* (Table 131). (2) *Bend tests,* including (*a*) cold-bend test and (*b*) quench-bend tests. (3) *A flattening test* for rivet stock.

154. Specimens for tension and bend tests should, with the exception of those for steel bar stock, be of full-size section of the stock. The specimen of steel bar, when the stock is less than 1½ in. thick, should be of the same thickness as the material after rolling. The piece may be machined to the form of Fig. 103 or with edges parallel. When the steel bar stock is over 1½ in. thick, the tension-test specimen may be of round section, similar to Fig. 104; the bend-test specimen may be machined down to 1 × ½ in. section, and in testing bent around a pin 1 in. in diameter.

155. The cold-bend tests for rivet, staybolt and bar steel are as follows: For stock less than ¾ in. thick or in diameter,

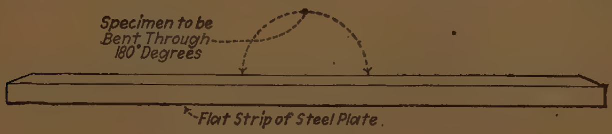


FIG. 113.—Test specimen before bending.

the cold specimen should bend through 180 deg. flat upon itself (Figs. 113, 114, 115 and 116) without cracking on the outside of the bent portion. For steel bar stock over ¾ and including 1¼ in. in thickness or diameter, the specimen should

bend around a pin of a diameter equal to the diameter (Fig. 111) or thickness of the piece; when the material exceeds 1¼ in. in thickness or diameter, the pin should have a diameter of twice the thickness or diameter of the specimen.

NOTE.—Fig. 117 shows a test sometimes made on staybolt material but the threading is not required by the A.S.M.E. CODE. Fig. 118 also shows a test for staybolt stock in tension which is not now generally

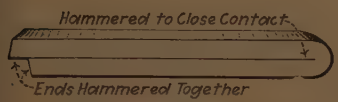


FIG. 114.—Bending test applied to specimen of steel bar stock.

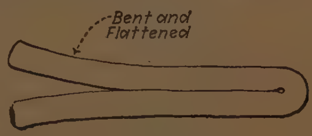


FIG. 115.—Bending tests on mild shaped specimens.

specified. This is a test for toughness and tenacity. It is made by screwing each end of a sample bolt into nuts made from pieces of the plate to be stayed (Fig. 118) and imposing on the specimen so prepared a pulling load. If it fails by the bolt pulling apart, the load per square inch of net cross-section at the instant of failure is taken as a measure of its strength. But if it fails due to the nuts stripping the threads off the ends, the corresponding load is the measure of its strength. In the first case a tensile stress determines the result, in the second a shearing stress.

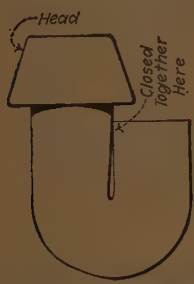


FIG. 116.—Rivet after being subjected to bending test.

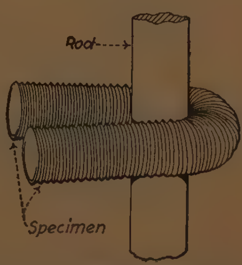


FIG. 117.—Obsolete test for malleability of stay-bolt stock.

The product of one-half the thickness of the plate ($T \div 2$, Fig. 119) by the circumference, C, of the bolt at one-half the height of the thread gives the mean sectional area of the metal opposed to shear.

156. The quench-bend test is required for rivet and staybolt steel. The specimens are the same as those used for the cold-bend tests. After the specimens have been heated to

a cherry-red (in darkness) they are quenched in water, which is at a temperature of from 80 to 90 deg. fahr. They are then given the cold-bend test (Sec. 155). This test is intended to determine whether or not the material has hardening characteristics which would render its use dangerous in boiler construction.

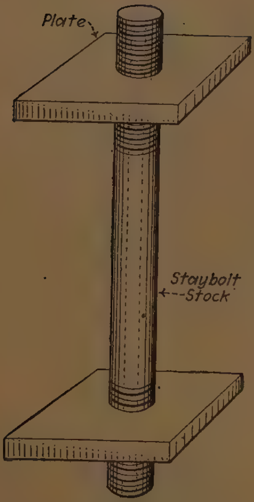


FIG. 118.—Obsolete method of preparing specimen of stay-bolt stock for tension test.

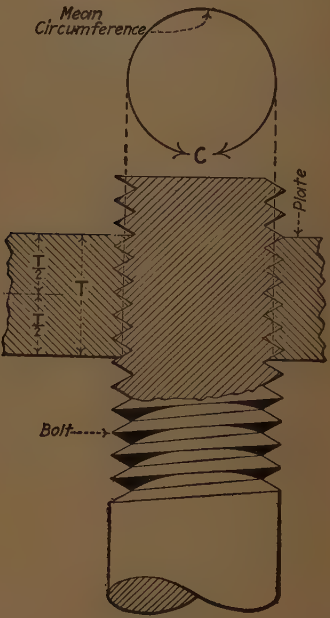


FIG. 119.—Computing area of metal opposed to shear.

157. A flattening test for rivet steel is also specified. The rivet head should flatten (Fig. 120), while hot, to a diameter 2½ times the diameter of the shank, without cracking at the edges.

158. The tests for rivet and staybolt iron, and for refined wrought-iron bars are: (1) *Tension tests* (Table 131). (2) *Bend tests*; (*a*) cold-bend, (b) hot-bend for rivet iron and refined wrought iron bars, (c) quench-bend for staybolt iron. (3) *Nick-bend tests.* (4) *Etch tests.*

159. The tension and bend tests for iron are similar to those for steel. It is impracticable to describe these tests

in detail in the limited space available in this book. For further information the reader is referred to the A.S.M.E. CODE.

160. A nick-bend test for iron is made by nicking the test piece with a chisel and then (Fig. 112) breaking the specimen. This enables observation of the nature of the metal which should not be crystalline, with the exception that refined wrought-iron bars may show not more than 10 per cent. of crystalline area.

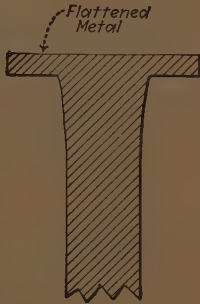


FIG. 120.—Rivet after flattening test.

161. The etch test on iron is made by polishing or grinding smooth the surface of a cross-section of a specimen and then etching it with a solution composed of one part concentrated hydrochloric acid and one part concentrated sulphuric acid. This test is for determining if there is steel in the specimen; there should be none.

NOTE.—When etched as above, steel presents a uniform, glistening white surface which has a frosted white appearance. Wrought iron presents a black and gray striated appearance, the arrangement of which indicates the piling of the iron.

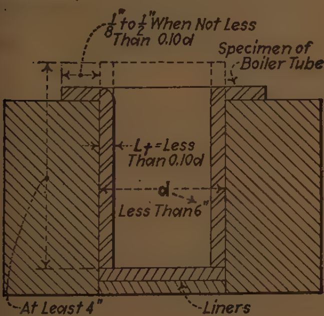


FIG. 121.—Flange test for tube.

162. Tests for lapwelded and seamless boiler-tubes are: (1) *Flange test.* (2) *Flattening test.* (3) *Hydrostatic test.*

163. The flange test for boiler-tube is made to determine malleability.

EXPLANATION.—For tubes not more than 6 in. diameter, having a thickness less than 10 per cent. of the outside diameter, provided the thickness does not exceed No. 6 B.W.G. (0.203 in.), a test specimen not less than 4 in. in length (Fig. 121) shall have a flange turned over at right angles to the body of the tube without cracking or showing any flaw. The flange shall have a width, measured as in Fig. 121, of 0.1 the outside diameter of the tube for tubes up to 5 in. in diameter and a width of ½ in. for larger tubes. For other tubes the flange test is not required. In making the flange test, the tube may first be flared with a flaring tool and then be flattened down with a flatter.

164. A flattening test is also required of boiler tubes. A test specimen 3 in. long should stand flattening (Fig. 122) between two parallel plates until the distance between the plates is not over 5 times the thickness of the tube wall. If the tube is lapwelded, the weld should be at the point of maximum bend. Cracks or flaws should not appear.

NOTE.—In Fig. 123 are shown some specimens of lapwelded steel boiler tubes (National Tube Company) as they appeared after pressure had been applied to them endwise in a hydraulic press. The specimens withstood this special test without fracturing.

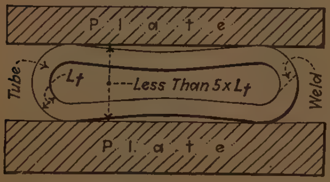


FIG. 122.—Flattening test for boiler tubes.

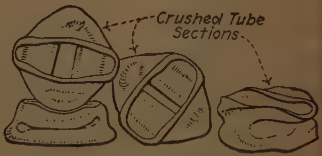


FIG. 123.—Tested sections of steel boiler-tubes.

165. The hydrostatic test for boiler tubes is made by applying internal pressure. Tubes under 5 in. in diameter should stand 1,000 lb. per sq. in. Tubes over 5 in. in diameter should stand a pressure of 800 lb. per sq. in., providing that the fiber stress in the metal does not exceed 16,000 lb. per sq. in., in which case the testing pressure should be

(1) $$P = \frac{32,000L_t}{d_i} \qquad \text{(pressure, lb. per sq. in.)}$$

Wherein: P = test pressure in pounds per square inch. L_t = thickness of tube wall in inches. d_i = inside diameter of the tube, in inches. Lapwelded tubes should be struck near both ends with a 2 lb. steel hammer while the pressure is being applied.

166. Cast steel is a grade of steel which can be cast into regular shapes by pouring the molten metal into molds. It contains (Table 131) about the same proportion of carbon as does mild steel. This is necessary to secure a condition of fluidity that will insure a ready flow of metal into all parts of the mold. Cast steel was formerly used to some extent in sectional boilers

as a material for headers. However, its application for this service has been practically discontinued. The difficulty of producing homogenous castings is the chief objection against the use of cast steel in boiler construction. When made without defects, however, the castings are very tough and tenacious.

167. Formerly much cast iron was used in boiler construction. Plain-cylinder boilers often had cast iron heads. Sectional boilers also have been built of cast iron. Now, however, its utilization in boiler construction is restricted chiefly to mountings, supports, handhole and manhole plates, and for pressure-sustaining parts where the boiler is designed for comparatively low pressure service, as for example, house-heating. The best practice dictates the use of stamped or forged steel for irregularly-shaped parts which are subjected to pressure.

168. Cast iron is a dangerous material to use when high steam pressures are concerned. This is chiefly because it is impossible to determine from its external appearance the internal condition of a casting. Large slag-holes and cavities made by gas bubbles may be hidden under an apparently sound exterior surface. Also there may be severe local strains (on account of unequal cooling in the mold) in the grain of the metal. Even where castings are sound, there is still the danger of sudden cracking caused by the extreme variations of temperature prevailing in the generation of steam.

NOTE.—About the only characteristic of cast iron to recommend it as a boiler material is its practical imperviousness to ordinary corroding elements. This property renders it peculiarly adapted for use in the making of mud-drums. Until recent years it was so utilized in water-tube boilers of the leading types. Mud-drums of these boilers are now made of wrought steel or cast steel.

169. Malleable cast iron is produced by annealing ordinary cast-iron castings. This is done by raising the temperature of the castings to a red heat while in contact with oxide of iron which may be in the form of red hematite ore. Thereby a large proportion of the carbon in the castings is removed, by the process of chemical reduction. Thus malleability

results from the expulsion of much of the original carbon content. Malleable iron is allowed (A. S. M. E. Code) for use in cross-pipes, headers, and cross-boxes for presures up to 200 lb. per sq. in., provided that the cross-section of such parts will fall within a 7 in. × 7 in. rectangle.

Note.—The tensile strength of malleable iron is from 37,000 to 50,000 lb. per sq. in. It can, unless too thick, be bent and worked to some extent like wrought iron. The decarbonization seldom extends to a depth of more than 1/4 in. from the outer surface of the casting. High temperatures impair its strength.

170. Tests on steel, gray iron, and malleable castings (Table 131) cannot be discussed fully here. Steel castings are subjected to tension, bend, and destruction tests. Gray iron castings are tested in tension and transversely (using an "Arbitration Bar"). Malleable castings are also tested in tension and transversely. See the A.S.M.E. Boiler Code for details.

171. Copper has characteristics which commend it as a boiler material for certain services. It is very ductile and malleable. It is a good conductor of heat and resists oxidation. The tensile strength of copper plates is about 34,000 lb. per sq. in. Copper is used largely in Europe for stay bolts and for the fire-boxes of locomotive boilers. It has long since become obsolete in the United States for these purposes. Its high cost prohibits its use as a staple material for boiler-making. But even so, it is generally inferior to mild steel for the all-around purposes of boiler construction.

172. Bronze is an alloy of copper and tin. Its use in boiler work is confined to parts of valves and accessories where toughness and ability to resist corrosion are specially desirable qualities. The tin improves the fluidity of the molten alloy. It also increases the hardness of the finished casting, but diminishes its ductility.

173. Brass is an alloy of copper and zinc. It is widely used in the manufacture of boiler fittings. By reason of its comparative immunity from corrosion and incrustation, it is also regarded favorably as a material for the feed-water connections to steam boilers. In Europe it is used in the flue-

tubes of locomotive boilers. Its high heat conductivity recommends it for this service.

QUESTIONS ON DIVISION 5

1. Name some of the most common metals that are used in steam boiler construction.
2. Why is it important to consider carefully the quality of the materials that are used in steam boiler construction?
3. To what abuses may a boiler be subjected?
4. What kind of stresses are imposed upon the materials in a steam boiler?
5. What is *wrought iron*? *Charcoal iron*?
6. Describe briefly the manner of making a sheet of wrought iron.
7. What is *low-carbon steel*?
8. What process is used in making boiler steel?
9. What is done with steel when it comes from the furnace in a molten state?
10. State some distinguishing differences between wrought iron and steel.
11. What kind of steel is specified by the A.S.M.E. Boiler Code for boiler shells?
12. Name some of the principal elements found in mild steel. Why are they in the steel?
13. What is meant by each of the following terms: *tenacity*, *elasticity*, *hardness*, *ductility*, *malleability*, *toughness*, *resilience*, *homogeneity*?
14. Describe the effect of carbon upon tensile strength of steel.
15. What makes boiler plate hard? Why not make boiler plate very hard?
16. What makes steel plate brittle?
17. What is the effect of the presence of phosphorus in steel?
18. What is the effect of sulphur in steel?
19. Discuss the effect of the presence of manganese in steel plate.
20. Mention some of the grades of steel used in making boilers and tell for what each grade is used.
21. What is the effect of high temperature upon steel?
22. Mention some of the important tests which are required for determining the fitness of iron and steel for use in a boiler?
23. How is a tension test made?
24. Describe the use of the extensometer.
25. What is meant by *elastic limit*? *Yield point*?
26. Which is the easier to determine and why, elastic limit or yield point?
27. Does the area of the cross-section of a test piece change when it is pulled in two?
28. How are tension test specimens obtained and prepared for testing?
29. What is meant by resilience?
30. How is ductility of a material determined?
31. How does the compressive strength of steel compare to its tensile strength?
32. What shearing strength is required of rivet steel?
33. What are the most important physical tests for boiler plate steel?
34. How is a test specimen cut from plate steel and why?
35. How is the cold-bend test made on boiler-plate steel?
36. How may the homogeneity of a specimen be determined?
37. What tests are specified for rivet, staybolt, and bar steels?
38. How should the specimen be prepared?
39. What differences are noted between cold-bend tests for steel plate and bar materials?
40. Describe a quench-bend test. Flattening test for rivet stock.
41. What is a nickbend test? For what materials is it specified?
42. What is the purpose of an etch test?
43. How are boiler tubes tested?
44. How is cast steel used to make irregular forms for use in boiler construction? Why is it undesirable?

45. Why has cast iron been discarded as a material of which to make fittings for a boiler?

46. What good characteristic has cast iron?

47. How is malleable iron produced and what are its charactersitics?

48. What tests are specified for steel castings? Gray iron castings? Malleable castings?

49. Why is copper not used extensively in boiler construction?

50. What characteristics has bronze which makes it suitable for valve parts? Brass?

DIVISION 6

STRESSES IN AND STRENGTHS OF STEAM BOILERS

174. In considering the subject of stresses in and strengths of steam boilers, the principles involved will first be discussed as applying to an imaginary, seamless, cylindrical, metal shell which is subjected to an internal pressure. Subsequently, it will be shown how these basic theoretical principles may be modified to permit their application to actual steam-boiler design.

175. The technical meanings of the words "stress" and "strain" should be understood. The *stress* in a material is the internal resistance, offered by the molecules of the material, which opposes deformation, or change of shape. Stress balances an external force which may be a push, pull, pressure, weight or load. Force is the cause; stress is a result. Since the stress in a material is always just sufficient to counterbalance the force which is applied, it is always equal, but opposite in direction, to the applied force. Stress is sometimes, though incorrectly, thought of as a load. But it will be under stood here to be the internal resistance offered by the material to the load. Stress is measured in the same units as force, *i.e.*, in pounds or any other unit of weight. A strain is an alteration, or deformation, in size, form, or volume due to the application of a force. Strain may be considered as the stretch due to a load.

Example.—If a strip of boiler plate has a weight of 5,000 lb. suspended from one end, a stress of 5,000 lb. exists at every cross-section of the strip.

Example.—If a steam pressure of 100 lb. per sq. in. be carried in a boiler, then there is a tendency to push the boiler apart, but the internal stress opposes the rupture of the shell. The shell is strained, or stretched, according to the intensity of the pressure in it.

176. Stresses in a boiler may be due to tension, compression, shear, flexure, torsion, or other combinations of tension,

compression, and shear may exist. A *tensile stress* is the stress opposed to pulling apart, or tension. A *compressive stress* is produced by a pushing together, crushing, or compression. A *shearing stress* is due to two forces tending to slide one part of a material past another. The forces act in parallel planes, usually very near each other. Such action is produced by shears which are used for cutting materials. *Flexural stress* is produced by bending. It is a combination of tensile and compressive stresses. It is the stress produced in a horizontal floor beam when it is loaded. The fibers above the neutral axis are in compression and those below the neutral axis are in tension. *Tortional stress* is produced by forces which cause a twisting or torque. Such a stress is a complex combination of tensile, compressive, and shearing stresses. Ordinarily, however, only the shearing stress is considered in torsion computations.

NOTE.—Since the pressure or force which is applied externally to a material is numerically equal to the stress which the pressure sets up in the material, it is often convenient to solve practical problems by considering the applied forces alone. This procedure will, in general, be followed in the succeeding discussion. But it should be remembered that the external force produces the internal stress and that it is the stress which is actually of importance when considering the strength of a material.

177. Steam Confined In Any Vessel Exerts The Same Pressure In Every Direction.—That is, the pounds push is the same against each and every square inch of the interior surface of the vessel. This is merely a statement of an observed fact.

178. All Of The Stresses Produced By The Contained Steam Pressing On The Interior Of A Shell May Be Resolved Into Longitudinal And Transverse Stresses.—Thus, while, as above stated, the steam pressure acts with equal force on every square inch of the interior surface of a shell (or any vessel), the combined effects of all of the resulting stresses may, if convenient (as will be explained), be considered as comprising only two resultant stresses: (1) *A longitudinal stress*, and (2) *a transverse stress*. The transverse stress is one in a direction at right angles to the axis of the shell. It resists forces (Fig. 124) which tend to tear the shell apart lengthwise. The

longitudinal stress is one in a direction along the axis of the shell. It resists forces (Fig. 125) which tend to tear the shell across or to separate it endwise.

Thus, any cylindrical vessel which is subjected to internal pressure, may fail in either one of two ways: (1) *Due to*

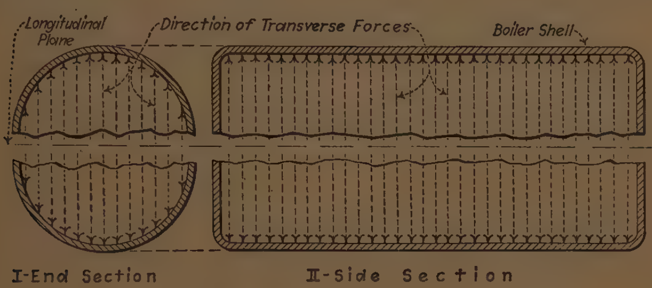


FIG. 124.—Illustrating "Transverse" forces. (The transverse forces produce transverse stresses.)

transverse forces, Fig. 124, *which tend to pull the shell apart side wise or along a longitudinal plane.* (2) *Due to longitudinal forces, Fig.* 125, *which tend to pull the shell apart endwise or along a transverse plane.* The transverse stress (which resists longitudinal rupture) and its effects, will be considered first,

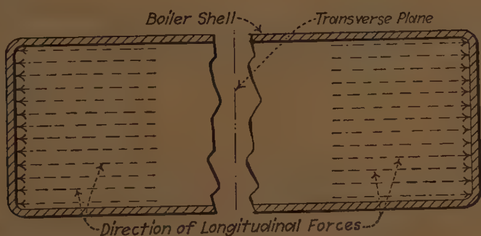


FIG. 125.—Illustrating "Longitudinal" forces. (The longitudinal forces produce longitudinal stresses.)

and then the longitudinal stress, which resists transverse rupture, will be discussed.

NOTE.—Since the transverse and longitudinal stresses act at right-angles to each other (Fig. 126), they have no effect on each other. Therefore, they can and should be considered independently. In any cylindrical shell, the unit transverse stress is, as will be shown, always the

greater. In a spherical shell (Fig. 127) the "longitudinal" and the "transverse" stresses are, obviously, equal.

179. Steam in a cylindrical shell exerts a uniform pressure along radial lines (Fig. 128) against all points on the interior wall of the shell. (This is in addition to the longitudinal

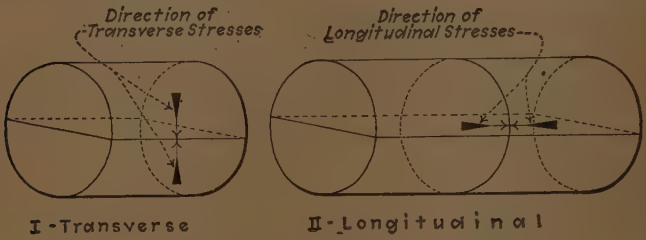


FIG. 126.—Showing how the transverse and longitudinal stresses are directed at right angles to each other.

pressure, which will be considered later.) The obvious action of the steam pressure, which thus acts radially from the axis of the shell and which is distributed uniformly over the interior surface as indicated by the arrows in Fig. 128, is to tend to preserve the cylinder from distortion from outside forces. It

FIG. 127.—Spherical shell.

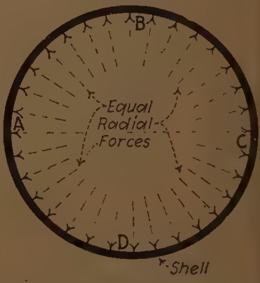


FIG. 128.—Illustrating direction of pressure on wall of cylindrical shell.

tends to round out any initial variations from the true circular contour. Hence, the sheets of circular boiler-shells and drums are self-supporting and require no bracing to resist distortion.

180. The transverse stress due to the steam in a cylindrical boiler tends to prevent rupture of its wall (Fig. 126-*I*) length-

wise, along any two diametrically opposite lines in its circumference. With perfectly-homogeneous seamless-metal vessel, a bursting pressure would tend to rupture the shell simultaneously along an infinite number of diametrically-opposite longitudinal lines. However, in an actual pressure vessel, there is always some line of least resistance to failure by lengthwise rupture. In a welded steel shell, it would probably be along a weld. In a boiler-shell, it would be along a riveted seam.

181. It Is The Total Transverse Force, Acting In A Single Direction Only, That Is Effective In Rupturing The Shell Longitudinally.—Since the internal pressure acts radially in all directions (Fig. 128) from the axis of the cylinder, it might be assumed that the total force which tends to rupture the shell along *AC* would be the force against the upper half, *ABC*, plus the force against the lower half, *ADC*. Such an assumption would be incorrect, as will be explained. The force which tends to rupture is that imposed on only one-half of the shell, either *ABC* or *ADC*. Note the following example and then the explanation below.

Example.—If the total transverse force imposed against *ABC* in Fig. 128 is 100,000 lb., and that against *ADC* is 100,000 lb., then the total pressure tending to split the shell along the line *AC* would be 100,000 lb.—not 200,000 lb.

Explanation.—If the shell of Fig. 128 has an internal transverse force of 100,000 lb. imposed on each of its halves, it would be stressed the same as though two weights of 100,000 lb. each (Fig. 129) were pulling against one another through the shell. If the shell is of insufficient strength to withstand the force, it would pull apart on line *AC*. One weight, W_1, constitutes merely the equal and opposite force with which every applied force must be resisted. Thus, a man (Fig. 130) pulling against a boy who is holding the rope, can pull no harder than the boy pulls against him. If the boy pulls 50 lb., the man must also pull 50 lb. A spring balance inserted in the rope would register 50 lb. If the man pulls harder than the boy, he will jerk the boy off his feet. In any case, the stress, at any location in the rope, will equal only what

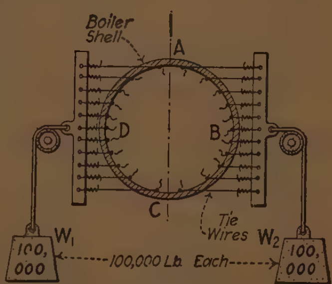


Fig. 129.—Transverse forces tending to pull shell asunder.

one of them pulls. It will *not* be the sum of what both of them pull. The tension in the rope is 50 lb.—not 100 lb. A solidly-set post might (Fig. 131) replace the boy. Then, when the man pulls with a force of 50 lb. against the post, the post would, obviously, be pulling against or holding him with a force of 50 lb. Again, a spring balance inserted in the rope would read 50 lb. Figs. 132 and 133, wherein weights are substituted for the man and boy, respectively, and a screw-eye in the floor for the post, further explain the situation.

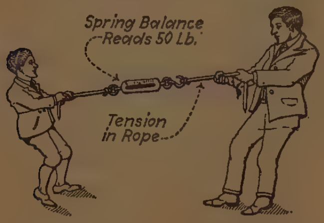


FIG. 130.—Every stress must be opposed by an equal and opposite force.

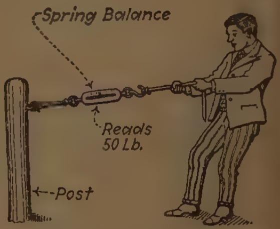


FIG. 131.—The post always pulls just exactly as much as does the man.

182. The Area Against Which The Pressure Is Assumed To Act, Is The Projected Area That Lies At Right-angles To The Direction Of Pressure Under Consideration.—Why this is true will be explained later. For the present, consider this example.

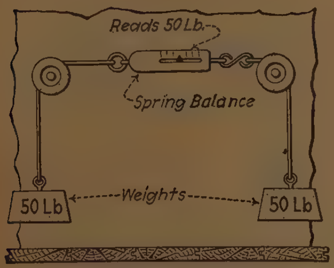


FIG. 132.—Equal and opposite forces.

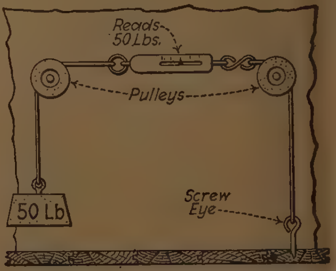


FIG. 133.—The screw eye always "pulls" just exactly as much as does the weight.

EXAMPLE.—What is the total force tending to burst the ring in Fig. 134? This represents an imaginary 1-in. length of seamless steel shell of a boiler 30 in. in diameter under an internal pressure of 100 lb. per sq. in. SOLUTION.—Its projected area (see explanation below) is: 30 *in.* × 1 *in.* = 30 *sq. in.* The pressure on every square inch is 100 lb. Hence, the force tending to burst the shell along the line *AB* is:

30 × 100 = 3,000 *lb.* Obviously, since this force must be divided equally between the two sections of the shell in tension at *A* and at *B*, that at *A* is 1,500 lb. and that at *B* is 1,500 lb.

183. The projected area (Fig. 135) is, in this connection, the area crosswise to the direction of pressure. It is the area which the thing would present to the human eye if it were held up and looked at in the direction of the arrows (Fig. 134) which indicate the direction of the applied internal pressure. It is the area of the shadow (Fig. 135) which would be cast by rays of light parallel to the direction of pressure. Thus, *the projected area, against which the pressure tending to burst a boiler longitudinally acts, is equal to the product of the internal diameter of the shell times the length of the shell under consideration.*

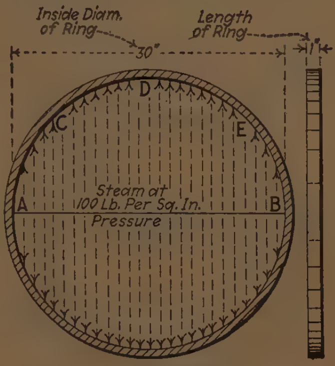


FIG. 134.—Illustrating direction of pressure acting to separate ring of shell plate on horizontal diameter.

EXAMPLE.—The projected area of the segment of the shell shown in Fig. 134 is: 30 *in.* × 1 *in.* = 30 *sq. in.* The projected area of the segment of a half-shell shown in Fig. 135–*I* is: 42 *in.* × 60 *in.* = 2,520 *sq. in.* (Note the other examples in Fig. 135.)

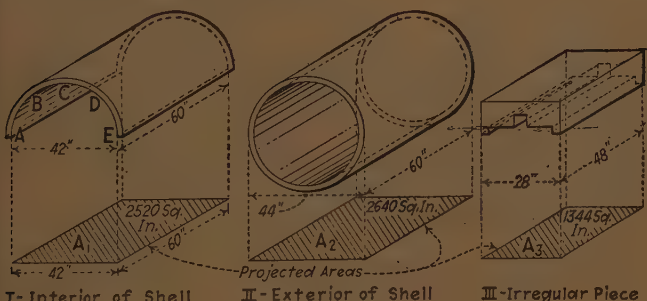


FIG. 135.—A_1, A_2, and A_3, are projected areas.

184. Why the projected area is taken instead of the circumferential area against which the steam pressure acts will now be explained. At first glance, it might appear that the

length of the half circle, *ABCDE*, in Fig. 135–*I* should be multiplied by the length of the shell, to obtain the area against which the effective pressure acts. That it would be incorrect to do this, will now be shown.

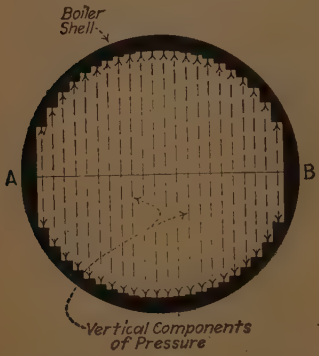


FIG. 136.—Illustrating vertical component of pressure on each semicircumference.

FIG. 137.—Illustrating horizontal component of pressure on each semicircumference.

EXPLANATION.—Imagine that the inside surface of the ring of Fig. 134 is a series of infinitely-small steps or corrugations. In Fig. 136 it is apparent that it is only the pressure exerted against those surfaces of the serrations which lie parallel to the diameter, *AB*, that is effective in tending to burst the shell along the line *AB*. That is, it is only this "vertical component of the pressure in all directions" that tends to burst the shell along *AB*. The pressure acting on those surfaces of the corrugations which lie at right-angles (Fig. 137) to the vertical diameter have no influence for or against separation along *AB*. This horizontal pressure is termed the "horizontal component of the total pressure." Hence, as above explained, the area in Fig. 134 against which the bursting pressure is actually effective is: 30 *in.* × 1 *in.* = 30 *sq. in.* In other words, the only forces which tend directly to produce rupture are those which act at right-angles to the line of rupture.

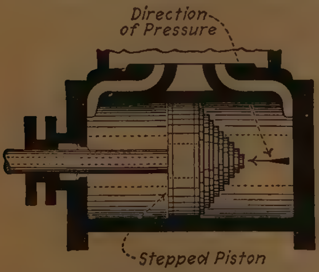


FIG. 138.—Stepped piston face.

Another viewpoint of this same situation (first suggested by Fred R. Low of POWER) may be obtained by considering the pushing action of the steam against an engine piston. A piston, which has its outer face turned into steps (Fig. 138) would, obviously, have exactly the same

area for the production of power as would a flat-surfaced one. Any steam thrust on one side, against a longitudinal face of one of the steps, would be counterbalanced by an exactly equal and opposite thrust from the other side. Only the steam thrust on the vertical faces is pushing the piston forward. Obviously, the total area of all of these vertical-face rings is precisely the same as that of a flat circle of the same overall diameter. Some further illustrations of this same situation are given in Fig. 139.

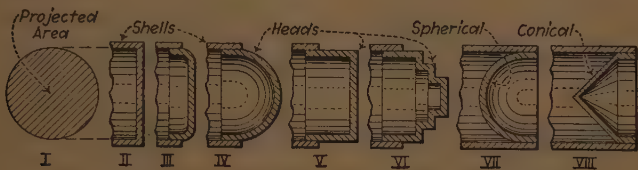


FIG. 139.—All have the same "projected area" as shown at *I*.

The reason just outlined would be as true if the steps were a millionth or a hundred-millionth of an inch wide. It follows that the pushing pressure against a conical surface (Fig. 140) or a concave surface (Fig. 141) would be exactly the same as against a flat surface of the same overall diameter. Hence, it is apparent that it is the projected area in the direction of the pressure under consideration (not the actual superficial area) which is effective in producing a bursting stress in a boiler-shell.

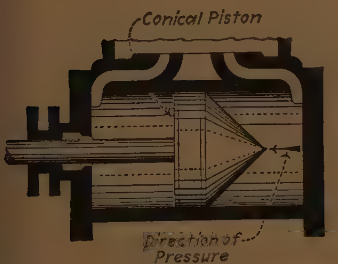


FIG. 140.—Conical piston face.

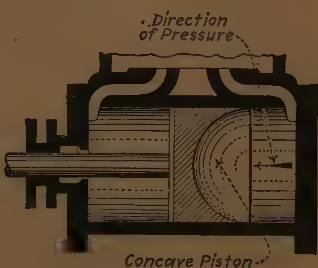


FIG. 141.—Concave piston face.

185. The formula for computing the total internal transverse rupturing force imposed on a cylindrical shell may now be developed. From the preceding statements it follows that to obtain this force it is merely necessary to multiply the projected area in square inches by the pressure in pounds per square inch imposed on it. The projected area is equal to

the product of the internal diameter and length. Expressing these operations as a formula:

(2) $$P_T = dLP_{gt} \quad \text{(force, pounds)}$$

and

(3) $$d = \frac{P_T}{LP_{gt}} \quad \text{(internal diameter, inches)}$$

and

(4) $$L = \frac{P_T}{dP_{gt}} \quad \text{(length, inches)}$$

and

(5) $$P_{gt} = \frac{P_T}{dL} \quad \text{(internal pressure, lb. per sq. in.)}$$

Wherein P_T = total force tending to rupture the shell lengthwise or longitudinally, in pounds. d = internal diameter of the shell in inches. L = internal length of the shell in inches. P_{gt} = internal pressure in pounds per square inch, gage.

EXAMPLE.—Applying this formula to the example already given: What would be the total transverse force tending to rupture an imaginary boiler (Fig. 134) 1 in. long and 30 in. internal diameter which is carrying steam at 100 lb. per sq. in. pressure? SOLUTION.—Substitute in formula (2): $P_T = dLP_{gt} = 30 \times 1 \times 100 = 3{,}000$ *lb.*

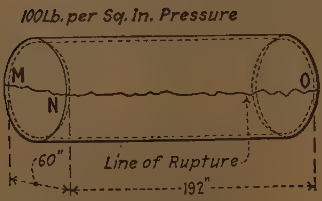


FIG. 142.—What transverse rupturing force imposed on shell 60 in. in internal diameter and 192 in. long inside with 100 lb. per sq. in. internal pressure.

EXAMPLE.—The total force tending to rupture the shell of Fig. 142 along the plane MNO would be; $P_T = dLP_{gt} = 60 \times 192 \times 100 = 1{,}152{,}000$ *lb.*

186. The formula for computing the transverse stress set up in one section only of the metal shell, or along the line of a riveted seam, will now be given. In computations relating to the strengths of boilers, it is customary to consider only the load imposed on one of the two sections of metal which are subjected to tension. That is, only the load assumed by ZW or XY in Fig. 143 is considered, rather than that assumed by both ZW and XY. Obviously, half of the total force is imposed on each section. Then, taking half of formula (2),

which gives the total imposed force, that is, dividing it by 2:

(6) $$P_T = \frac{dLP_{gt}}{2} \quad \text{(stress, pounds)}$$

Or, since the diameter, $d = 2$ times radius, r, or $d = 2r$, the equation may also be written:

(7) $$P_T = rLP_{gt} \quad \text{(stress, pounds)}$$

Wherein all of the symbols have the same meanings as specified above, except that P_T = transverse stress in one section only of the shell, in pounds. Also, r = internal radius of shell in inches.

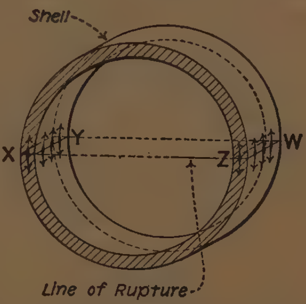


FIG. 143.—Illustrating rupturing forces in single section

EXAMPLE.—Taking the values used in the above example relating to Fig. 142, the transverse stress in one section of the shell would be: $P_T = dLP_{gt}/2 = (60 \times 192 \times 100) \div 2 = 576{,}000$ *lb.*

187. The resisting strength which a cylindrical shell offers to transverse rupturing pressure such as that which occurs in

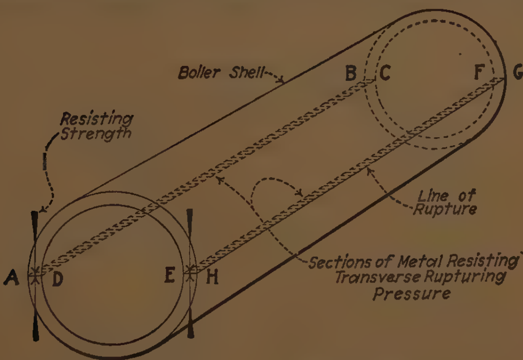


FIG. 144.—Sections of shell which resist bursting.

the steam boiler due to the confined steam, will now be considered. Obviously, resisting strength is offered by the two sections of metal (for example, *ABCD* and *EFGH* in Fig. 144 and *ZW* and *XY* in Fig. 143) which extend longitudinally the length of the shell along the assumed plane of rupture. The

resisting tensile strength of these sections can, as will be shown, be computed readily.

188. In boiler calculations no recognition is accorded to the resisting strength which is offered against transverse pressure by the ends or heads of the cylinder. It is apparent that the ends of the cylinder, particularly when they are flat, must increase, to some extent, the resisting strength against transverse pressure. The ends act like stays. But it is impossible to compute precisely the amount of the strength increase thus afforded. Hence, in practice it is disregarded entirely.

Note.—It is often assumed in practice that the possible increase in strength, due to the ends, offsets indeterminate elements of weakness, such as poor joints, imperfect metal, corrosion, and improper staying.

189. The formula for computing the safe total resisting strength of a seamless, cylindrical shell against transverse pressure (its derivation is given below) is:

(8) $$S_{Tt} = \frac{2L_tU_tL}{f}$$ (safe resisting strength, pounds)

and

(9) $$L_t = \frac{S_{Tt}f}{2U_tL}$$ (plate thickness, inches)

and

(10) $$U_t = \frac{S_{Tt}f}{2L_tL}$$ (tensile strength, lb. per sq. in.)

and

(11) $$L = \frac{S_{Tt}f}{2L_tU_t}$$ (length, inches)

also

(12) $$f = \frac{2L_tU_tL}{S_{Tt}}$$ (factor of safety)

Wherein S_{Tt} = safe resisting strength of the shell against internal transverse bursting pressure in pounds. L_t = thickness of the plate in inches. U_t = ultimate unit tensile strength of the metal in pounds per square inch. L = internal length of the shell in inches. f = assumed factor of safety.

The derivation of the above formulas is this: First, note (Sec. 188) that the resisting strength of the ends is disregarded. Each square inch of the shell plate section which is in tension offers a certain number of pounds resistance to rupture. Hence, to obtain the total *ultimate*

resistance to bursting, it is merely necessary to compute the total number of square inches of metal which opposes the bursting pressure, and multiply this area by the number of pounds per square inch which the metal will sustain. Then to obtain the safe resisting strength against bursting, the "ultimate" value, computed as above described, must be divided by the "factor of safety" (see Sec. 190 below). Expressing all of these operations in one equation, the working formula results, thus:

(13) $$S_{Tt} = 2L_tU_tL/f$$ (resisting strength, lb.)

EXAMPLE.—If the plate metal in the boiler of Fig. 142 is ½ in. thick and has an ultimate unit tensile strength of 50,000 lb. per sq. in., what, assuming a factor of safety of 5, is the total transverse bursting force which the boiler will safely sustain? SOLUTION.—The length is 192 in. Substitute in formula (7) above: $S_{Tt} = 2L_tU_tL/f = (2 \times 0.5 \times 50{,}000 \times 192) \div 5 = 1{,}920{,}000$ *lb.*

190. A "Factor of Safety" is the number which expresses the ratio which the ultimate strength of the material bears to the stress set up in the material.

EXAMPLE.—If the ultimate tensile strength of steel boiler-plate is 55,000 lb. per sq. in., and a boiler is so designed that only 11,000 lb. per sq. in. stress is set up in that plate, then: 55,000 ÷ 11,000 = 5 = *factor of safety*. Again, if the ultimate strength of the material is 55,000 lb. and the existing stress is 55,000 lb., then 55,000 ÷ 55,000 = 1 = *factor of safety*. That is, a factor of safety of 1 means that the material under consideration is stressed to its ultimate tensile strength. In effect, then, a factor of safety of 1 is, in reality, no "factor of safety" at all.

191. Table giving factors of safety for steam-boilers as recommended by the A.S.M.E. boiler code.

Boilers, Application and kind	*f.* Factor of safety	A.S.M.E. Code, 1918	
		Page	Par.
Boilers in service when code becomes effective: after first year following code adoption and during ensuing four years	4.0	97	379
Boilers in service when code becomes effective: after fifth year following code adoption	4.5	97	379
For domes when single-riveted to boiler	8.0	49	194
Power plant, new installations	5.0	43	180
Second-hand boilers	5.5	98	381
Steel, for hot-water and steam heating	5.0	90	340

192. The formulas for computing the safe unit transverse pressure which may be imposed on a seamless, cylindrical shell, or the safe plate thickness and diameter, or the safety factor may, as explained below, be derived from the preceding equation. The working formulas are:

(14) $$P_{gt} = \frac{2L_tU_t}{df}$$ (internal pressure, lb. per sq. in.)

Hence

(15) $$L_t = \frac{dfP_{gt}}{2U_t}$$ (plate thickness, inches)

Also

(16) $$U_t = \frac{dfP_{gt}}{2L_t}$$ (ult. ten. strength, lb. per sq. in.)

Furthermore

(17) $$d = \frac{2L_tU_t}{P_{gt}f}$$ (diameter, inches)

And

(18) $$f = \frac{2L_tU_t}{P_{gt}d}$$ (factor of safety)

Wherein P_{gt} = safe internal working pressure in pounds per square inch. L_t = safe thickness of shell in inches. U_t = ultimate unit tensile strength of the shell material in pounds per square inch. d = safe internal diameter of the shell in inches. f = factor of safety.

THE DERIVATION OF THE ABOVE FORMULAS is this: If a cylindrical shell is stressed transversely by internal pressure just to the safe resisting strength of its material, then under this condition, the *total internal transverse rupturing force* must just equal the safe resisting strength. That is, using the symbols specified above:

(19) $$P_T = S_{Tt}$$ (pounds)

Now substitute for P_T from (2) its equivalent, dLP_{gt}, and for S_{Tt} its equivalent, $2L_tU_tL/f$ from (8). Then:

(20) $$dLP_{gt} = \frac{2L_tU_tL}{f}$$ (2) and (8) in (19)

(21) $$P_{gt} = \frac{2L_tU_tL}{dLf}$$ (pounds per square inch)

The two *L's* cancel out, leaving:

(22) $$P_{gt} = \frac{2L_tU_t}{df}$$ (int. pressure, lb. per sq. in.)

EXAMPLE.—What would be the safe working pressure against longitudinal rupture for a seamless boiler, 60 in. in diameter, made of ½-in. steel plate, having a tensile strength of 50,000 lb. per sq. in.? Assume a safety factor of 5. SOLUTION.—A substitute in formula (14): $P_{gt} = (2 \times L_t \times U_t) \div (d \times f) = (2 \times 0.5 \times 50{,}000) \div (60 \times 5) = 166.7$ *lb. per sq. in.* = working pressure.

193. A formula for computing the safe unit transverse pressure in which the radius, r, instead of the diameter, d, is used is the form employed ordinarily in practice. The working formula, the derivation of which is given below, is:

(23) $$P_{gt} = \frac{L_t U_t}{fr}$$ (internal pressure, lb. per sq. in.)

Wherein all of the symbols have the meanings specified above.

THE DERIVATION OF THE ABOVE FORMULA is this: The diameter always equals twice the radius:

(24) $$d = 2r$$ (diameter, in.)

Now formula (14) may be written:

(25) $$P_{gt} = \frac{L_t U_t}{f} \times \frac{2}{d}$$ (pressure, lb. per sq. in.)

Then substituting for d, in the above, its equivalent, $2r$, from (24)

(26) $$P_{gt} = \frac{L_t U_t}{f} \times \frac{2}{2r}$$ (pressure, lb. per sq. in.)

The 2's cancel out, giving the working formula:

(27) $$P_{gt} = \frac{L_t U_t}{fr}$$ (safe int. pres., pounds per sq. in.)

194. The method of computing the bursting internal pressure with any formula which contains a factor of safety, f, is merely to use a value of unity, or 1, as a factor-of safety value. This, obviously, is equivalent to allowing no factor of safety at all. When this is done the significance of the symbols in the formula is changed somewhat, as is explained in the following Sect.

195. The unit transverse bursting of a seamless shell may be computed by using formula (22) with a factor of safety of untiy, or 1. It then becomes:

(28) $$P_{bt} = \frac{2L_t U_t}{d}$$ (bursting pressure, lb. per sq. in.)

Wherein P_{bt} = transverse internal bursting pressure in pounds

per square inch. All of the other symbols have the same meanings as above specified except that they indicate dimensions and properties of the metal when it is stressed to the bursting point.

196. The above formulas do not hold for thick-walled cylindrical shells, like that of Fig. 145 for example. With

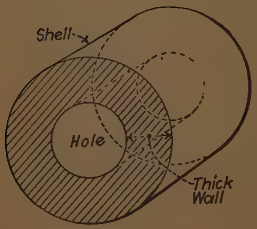


FIG. 145.—Thick-walled cylindrical shell.

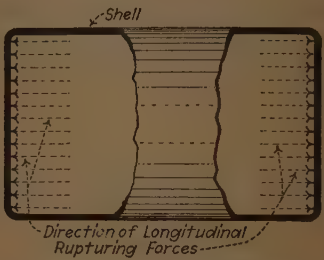


FIG. 146.—Illustrating direction of pressure acting to separate wall of cylindrical shell roundabout.

the thick-walled shell, additional modifying factors are introduced which it is unnecessary to consider here. The above quoted formulas will give correct results for all shell thicknesses which are used in ordinary steam-boiler construction.

197. The longitudinal stress which is developed by the internal pressure (Fig. 146) will now be considered. An internal pressure not only (Sect. 178) tends, due to its crosswise component, to split the shell lengthwise (Fig. 124), but it also tends, due to its lengthwise component, to blow the heads off or rupture it roundabout, as indicated in Figs. 125 and 146. (If the section of metal which is stressed is insufficient, the shell will then be thus ruptured.) This lengthwise component produces in the metal of the shell the longitudinal stress which is now to be examined. The longitudinal internal pressure component—due in a boiler to the contained steam—is, obviously, in a direction parallel to the axis of the cylinder.

NOTE.—These longitudinal forces act (Fig. 147) like two weights, one drawing on each head and tending to tear the heads from the shell. The effect of the longitudinal force in this respect is similar to that of the transverse force illustrated in Fig. 129 and described in accompanying paragraphs, which should be reviewed.

198. The formula for computing the total internal longitudinal rupturing force imposed on a cylindrical shell may now be derived. It is apparent from what has preceded that if the projected area (Fig. 139) of the head of the shell in square inches—which is the same as the internal cross-sectional area of the shell—be multiplied by the imposed internal pressure in pounds per square inch, the total longitudinal rupturing force will be the result. Now the area of any circle equals its *diameter squared times the constant* 0.7854. Hence, expressing the entire operation in a formula:

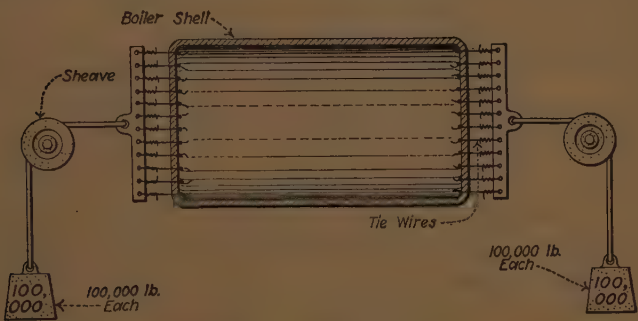


FIG. 147.—Longitudinal forces tending to pull shell asunder.

(29) $$P_L = 0.7854d^2P_{gl}$$ (total longitudinal force, lb.)

Hence

(30) $$d = \sqrt{\frac{P_L}{0.7854P_{gl}}}$$ (internal diameter, in.)

And

(31) $$P_{gl} = \frac{P_L}{0.7854d^2}$$ (pressure, lb. per sq. in.)

Wherein P_L = total longitudinal force in pounds tending to blow the head from the shell. d = internal diameter of the shell in inches. P_{gl} = internal pressure imposed on the shell in pounds per square inch.

EXAMPLE.—The force tending to blow the heads from the shell of Fig. 148 would be, using formula (29): $P_L = 0.7854\ d^2P_{gl} = 0.7854 \times 48 \times 48 \times 110 = 199{,}000$ lb. = total longitudinal rupturing force.

EXAMPLE.—The shell of Fig. 149 has an internal diameter of 24 in. The total force due to an internal pressure against the head tending

to blow it out, is 250,000 lb. What is the internal pressure? SOLUTION.—Substitute in formula (31): $P_{gl} = P_L/0.7854d^2 = 250,000 \div (0.7854 \times 24 \times 24) = 552.6$ *lb. per sq. in.*

199. The resisting strength which a cylindrical steel shell offers to longitudinal rupturing pressure, such as that which

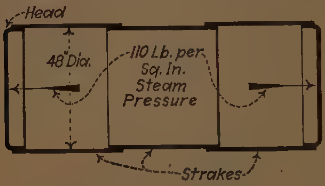


FIG. 148.—What force against heads? (NOTE.—A "Strake" is a shell plate.)

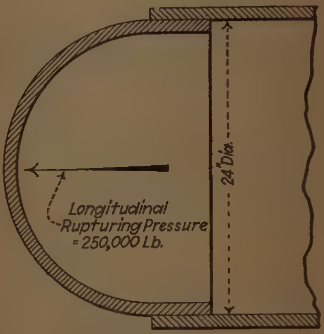


FIG. 149.—What internal pressure?

occurs in a steam boiler due to the confined steam, will now be considered. This tensile strength in a seamless shell would reside in the ring-shaped section of the metal (Figs. 150 and 151) extending circumferentially completely around the shell.

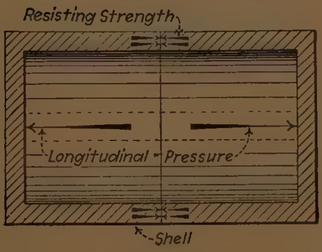


FIG. 150.—Illustrating resisting strength opposing longitudinal pressure.

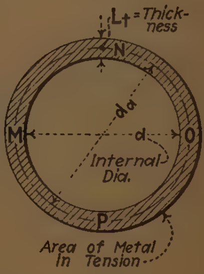


FIG. 151.—Area of metal in tension which resists longitudinal pressure.

In an actual boiler, the riveted joint between the head and the shell would afford this resisting strength.

200. The formula for computing the safe total resisting strength of a seamless cylindrical shell against longitudinal pressures follows. Its derivation is given below.

(32) $$S_{Tl} = \frac{3.1416 d L_t U_t}{f}$$ (Safe resisting strength, lb.)

and

(33) $$d = \frac{S_{Tl} f}{3.1416 L_t U_t}$$ (internal diameter, in.)

and

(34) $$L_t = \frac{f S_{Tl}}{3.1416 d U_t}$$ (thickness, in.)

also

(35) $$U_t = \frac{f S_{Tl}}{3.1416 d L_t}$$ (ultimate T.S., lb. per sq. in.)

Hence

(36) $$f = \frac{3.1416 d L_t U_t}{S_{Tl}}$$ (safety factor)

Wherein S_{Tl} = safe resisting strength against longitudinal pressure in pounds. d = safe inside diameter of the shell in inches. U_t = ultimate unit tensile strength of the metal of the shell in pounds per square inch. L_t = safe thickness of the shell in inches. f = assumed factor of safety.

THE DERIVATION OF THE ABOVE EQUATIONS is this: Each square inch of the annular section, *MNOP*, (Fig. 151) of the shell is capable of exerting a resistance against rupture equal to the ultimate tensile strength in pounds per square inch of the metal composing the shell. Therefore, if the area of this annular section, expressed in square inches, be multiplied by the unit ultimate tensile strength of the metal, the ultimate resisting strength will be the result. Then if the ultimate strength thus found be divided by the assumed factor of safety, the *safe* resisting strength will be obtained. Now the area of any annular or ring-shaped section (Fig. 151) is its *average circumference times its thickness*, L_t. To obtain average circumference, the average diameter, d_a, is multiplied by 3.1416. It is evident from Fig. 151 that average diameter $d_a = (d + \frac{1}{2}L_t + \frac{1}{2}L_t) = (d + L_t)$. Hence, *area* $= 3.1416(d + L_t)L_t$. Dividing by the assumed factor of safety, f, gives the safe load. Now, expressing the complete operation as a formula:

(37) $$S_{Tl} = 3.1416\,(d + L_t) \times \frac{L_t U_t}{f}$$ (longitudinal resisting strength, lb.)

But in practice, the thickness L_t added to the diameter, d_t results in a very small and inconsequential increase. Hence, it is omitted and the working formula then becomes:

(38) $$S_{Tl} = \frac{3.1416 d L_t U_t}{f}$$ (longitudinal resisting strength, lb.)

EXAMPLE.—The resisting strength of the steel shell of Fig. 152 against longitudinal pressure, assuming a factor of safety of 5 and a unit ultimate tensile strength of 50,000 lb. per sq. in. for the metal, would be: $S_{Tl} = (3.1416\ dL_tU_t) \div f = (3.14 \times 30 \times 0.5 \times 50{,}000) \div 5 = 471{,}000$ *lb.* (In practice, the constant 3.1416 is abbreviated to 3.14.)

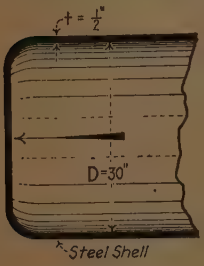


FIG. 152.—What is the longitudinal resisting strength of the shell?

201. The formulas for computing the safe unit longitudinal pressure which may be imposed on a seamless cylindrical shell, the safe plate thickness, the diameter, and the safety factor may, as explained below, be derived from the preceding equations, thus:

$$(39) \qquad P_{gl} = \frac{4L_tU_t}{df} \qquad \text{(safe internal pressure, lb. per. sq. in.)}$$

Hence

$$(40) \qquad L_t = \frac{dP_{gl}f}{4U_t} \qquad \text{(safe thickness, in.)}$$

and

$$(41) \qquad U_t = \frac{dP_{gl}f}{4L_t} \qquad \text{(ultimate T.S., lb. per sq. in.)}$$

$$(42) \qquad d = \frac{4L_tU_t}{P_{gl}f} \qquad \text{(diameter, in.)}$$

Wherein P_{gl} = safe longitudinal internal pressure in pounds per square inch. L_t = thickness of shell material in inches. U_t = ultimate unit tensile strength of the material in pounds per square inch. d = internal diameter of shell in inches. f = factor of safety.

THE DERIVATION OF THE ABOVE EQUATIONS is this: If a cylindrical shell is stressed longitudinally (Fig. 150) by internal pressure just to the safe resisting strength of the material, then under this condition the *Total Internal Longitudinal Rupturing Force* must be just equal to the *Safe Resisting Strength Against Longitudinal Pressure.* That is, using the symbols specified above, $P_L = S_{Tl}$. Now for P_L substitute from (29) its equivalent, $0.7854d^2P_{gl}$, and for S_{Tl} its equivalent, $3.1416dL_tU_t/f$ from (32). Then:

$$(43) \qquad 0.7854d^2P_{gl} = \frac{3.1416dL_tU_t}{f} \qquad \text{(29) and (32) in (43)}$$

Then solving for P_{gl}:

(44) $$P_{gl} = \frac{3.1416dL_tU_t}{0.7854fd^2} \quad \text{(lb. per sq. in.)}$$

This simplifying the above to the working formula:

(45) $$P_{gl} = \frac{4L_tU_t}{df} \quad \text{(safe pressure, lb. per sq. in.)}$$

EXAMPLE.—What is the safe steam pressure against roundabout rupture that may be carried in a seamless steel shell 60 in. in diameter made of ½-in. thick steel plate which has a tensile strength of 50,000 lb. per sq. in.? Assume a safety factor of 5. SOLUTION.—Substitute in formula (39 or 45): $P_{gl} = 4L_tU_t/df = (4 \times 0.5 \times 50{,}000) \div (60 \times 5) =$ 333.3 *lb. per sq. in.*

202. The unit longitudinal bursting pressure of a seamless shell may be computed with formula (39) by assuming a factor of safety of 1. The working formula then becomes:

(46) $$P_{bl} = \frac{4L_tU_t}{d} \quad \text{(lb. per sq. in.)}$$

Wherein P_{bl} = internal pressure in pounds per square inch which would cause bursting of the shell in a roundabout direction. All of the other symbols have the same meanings as above specified, except that they indicate dimensions and properties of the metal when stressed to the bursting point.

203. A seamless homogeneous cylindrical shell of uniform thickness is twice as strong against roundabout rupture as against longitudinal rupture. That is, the unit stress on the circumferential seams is half that on the longitudinal seams. The formula (46) for longitudinal internal bursting pressure which causes roundabout rupture is: $P_{bl} = 4L_tU_t/d$. The transverse internal bursting pressure which causes longitudinal rupture is (Formula 28): $P_{bt} = 2L_tU_t/d$. Obviously, the bursting pressure in the first case is just twice as great as that in the second. That is, it requires twice the pounds-per-square-inch internal pressure to rupture the shell roundabout as it does to rupture it lengthways. But, in any given shell the same pound-per-square-inch steam pressure acts both longitudinally and transversely. Hence, there is, in any given cylindrical shell, twice as much load imposed on the longitudinal as on the transverse seams. This is the reason for making the circular seams of boilers single-riveted, when

the longitudinal seams are double riveted and even triple riveted. It is merely a matter of preserving the proportions.

Example.—The same dimensions are used in the examples under formulas (14) and (39). For the safe transverse pressure, using formula (14), the result is 166.7 lb. per sq. in. For the safe longitudinal pressure, using formula (39), the refult is 333.3 lb. per sq. in. The first value is just half the second. Other similar examples will further verify the rule.

204. The stresses existing in a spherical shell due to an internal pressure and the resisting strength which the shell offers thereto may be computed readily. Obviously, from the preceding discussion, the internal stress due to internal pressure in a hollow sphere (Fig. 127) is the same on any diametral plane,

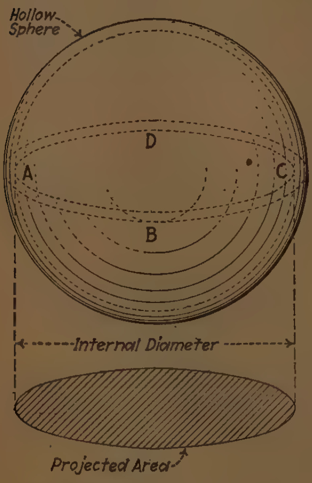


Fig. 153.—Hollow sphere.

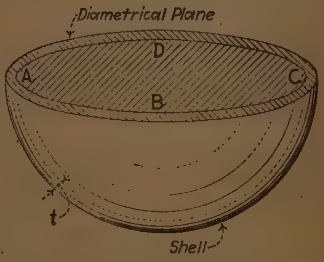


Fig. 154.—Illustrating diametrical plane.

AB, *CD*, or *EF*. The formulas specified for the computation of longitudinal pressures in a cylindrical shell and of the resistance against these pressures apply, without modification, to the hollow sphere. The projected area (Fig. 153) is the internal area on any diametral plane, as for example, *ABCD*, Fig. 154.

Example.—What safe internal steam pressure will the steel hollow sphere of Fig. 155 safely sustain? Its internal diameter is 24 in. Thickness of plate, which has an ultimate tensile strength of 50,000 lb. per sq.

in., is ½ in. Assume factor of safety of 5. SOLUTION.—Substitute in formula (39): $P_{gl} = 4L_tU_t/df = (4 \times 0.5 \times 50{,}000) \div (24 \times 5) = 833$ *lb. per sq. in.*

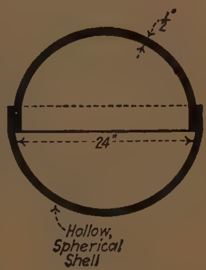


FIG. 155.—What pressure will the shell sustain?

205. How the foregoing theoretical principles relating to seamless cylindrical shells are applied in the design of actual power plant steam boilers will now be explained. The outstanding difference between the previously-discussed ideal seamless cylindrical shells and an actual boiler is that, in the real boiler, there must be riveted joints. It is impracticable to construct, without these joints, a steam power plant boiler. No riveted joint can be as strong as the plates which it joins, as will be explained in the next Div. But, as also will be described, the percentage tensile strength, which a riveted joint has as compared with the tensile strength of the perfect plates which form the joint, can be determined readily. This percentage-strength value is called the *efficiency* of the joint. (Riveted joint efficiencies are examined in detail in the succeeding Div.) "Efficiency" in this connection may relate to the relative strength of some weak part of the boiler structure other than the joint. This situation is covered in detail in the A.S.M.E. BOILER CODE.

206. To calculate the safe working steam pressure for a steam boiler of given dimensions, it is merely necessary to find, by using a preceding formula, the safe working pressure for a cylindrical shell of the same dimensions and made of the same material as the boiler. Then this safe pressure for the seamless shell is multiplied by the efficiency of the weakest joint or other element to obtain the maximum allowable working pressure for the boiler. All of these operations are combined in formula (47) for computing the maximum allowable working pressure.

NOTE.—As explained above, the unit transverse stress in a cylindrical shell is always twice as great as the unit longitudinal stress. Hence the longitudinal riveted joint is probably the weakest member. Therefore, the efficiency of the longitudinal joint is, as specified below, em-

ployed ordinarily in the "maximum working pressure" calculation. But if the ligaments between the tube holes (Par. 192), A.S.M.E. BOILER CODE, 1918) are the weaker, their efficiency is used instead.

207. The A.S.M.E. boiler code formula for computing unit maximum allowable working pressures for power boilers, using the same symbols as those in the A.S.M.E. CODE, is quoted below. Note that this formula, except that different symbols or letters are used, is, with the addition of the efficiency, E, identical with that given in formula (23).

(47) $$P_{MAW} = \frac{TS \times t \times E}{R \times FS}$$ (pres., lb. per sq. in.)

Hence

(48) $$TS = \frac{P_{MAW} \times R \times FS}{t \times E}$$ (tens. stress, lb. per sq. in.)

and

(49) $$t = \frac{P_{MAW} \times R \times FS}{TS \times E}$$ (thickness, inches)

and

(50) $$E = \frac{P_{MAW} \times R \times FS}{TS \times t}$$ (efficiency)

and

(51) $$R = \frac{TS \times t \times E}{P_{MAW} \times FS}$$ (radius, inches)

and

(52) $$FS = \frac{TS \times t \times E}{P_{MAW} \times R}$$ (safety factor)

Wherein: TS = ultimate tensile strength of boiler plate stamped on shell plates, as provided for in Par. 36 of the A.S.M.E. BOILER CODE, in pounds per square inch. t = minimum thickness of shell plates in weakest course, in inches. E = efficiency, of longitudinal joint or of ligaments between tube holes (whichever is the lesser) expressed decimally. R = inside radius of the weakest course of the shell or drum, in inches. FS = factor of safety, or ratio of the ultimate strength of the material to the allowable stress, see table 191 for factors of safety. P_{MAW} = maximum allowable working pressure, in pounds per square inch.

EXAMPLE.—What is the safe working steam pressure for a boiler 44 in. internal diameter having shell plates 5⁄16 (0.3125) in. thick with an ultimate tensile strength of 55,000 lb. per sq. in. The efficiency of the weakest joint is 0.82, and a factor of safety of 5 is to be allowed. SOLUTION.—Substitute in formula (47):—$P_{MAW} = (TS \times t \times E)\ \ (R \times FS) = (55{,}000 \times 0.313 \times 0.82) \div (22 \times 5) = 128$ *lb. per sq. in.* = maximum allowable working pressure.

EXAMPLE.—What is the largest safe internal diameter which a boiler to carry 150 lb. per sq. in. steam pressure can have, if it is made of 3⁄8 in. plate having an ultimate tensile strength of 50,000 lb. per sq. in.? The weakest joint is the longitudinal quadruple riveted joint which has an efficiency of 0.937. Factor of safety is to be 5. SOLUTION.—Substitute in formula (51): $(R = TS \times t \times E)/(P_{MAW} \times FS) = (50{,}000 \times 0.375 \times 0.937) \div (150 \times 5) = 23.4$ *in.* = radius. Hence the diameter would be: $2 \times 23.4 = 46.8$ *in.* or practically 47 *in.*

QUESTIONS ON DIVISION 6

1. What is the technical meaning of the word "stress?" "Strain?"
2. What kinds of stresses are found in a boiler?
3. If the pressure exerted by the steam in a boiler is such that it presses with a force of 35 lb. on a square inch of the end of the boiler, what will be the pressure exerted upon a square inch of the side of the boiler?
4. What are transverse and longitudinal stresses in a boiler shell?
5. How may a cylindrical shell fail when the pressure inside becomes great?
6. Why are the cylindrical plates of a cylindrical boiler shell self-supporting?
7. How does transverse pressure due to steam in a cylindrical vessel tend to rupture it?
8. Explain the fact that the pressure which tends to rupture a shell longitudinally is merely that imposed on one-half of it.
9. What is meant by the projected area of a cylinder?
10. Explain why the projected area is taken, instead of the circumferential area, in determining the force tending to rupture a cylinder longitudinally.
11. State and explain the formula for determining the total internal transverse rupturing force imposed on a cylindrical shell.
12. What is the difference between the above formula and the one used for determining the total stress set up in a longitudinal riveted seam?
13. Are the ends or heads of a boiler considered in determining the resisting strength against transverse pressure? Why?
14. State and explain the formula for determining the safe total resisting strength against transverse pressure.
15. What is meant by a *factor of safety*?
16. State and explain the meaning of the formula for computing the safe unit transverse pressure which may be imposed on a boiler shell.
17. How is this formula of Question 16 derived?
18. Demonstrate the change that takes place in the formula for determining the safe unit transverse pressure when the radius is used instead of the diameter.
19. If a formula is given by which the *safe* pressure in a shell may be determined, how is the formula altered so that it will give the *bursting* pressure for that shell?
20. State and demonstrate the derivation of the formula for determining the unit transverse bursting pressure of a seamless shell.
21. What is the tendency of the lengthwise component of the internal pressure in a boiler?

22. Explain the formula for determining the total longitudinal rupturing force imposed upon a cylindrical shell.

23. How is the longitudinal resisting strength of a cylindrical boiler determined? State and explain the formula.

24. Write the formula which may be used for computing the safe unit longitudinal pressure which may be imposed on a seamless cylindrical shell. Give its derivation.

25. What is the relation of the unit longitudinal to the unit transverse stress set up in a shell of uniform thickness?

26. How is the unit longitudinal bursting pressure of a seamless shell determined?

27. How may the stresses set up in a spherical shell be determined?

28. What determining factor must be considered in practical design of steam boilers?

29. What is meant by the *efficiency* of a riveted joint?

30. How are the safe working pressures determined for boilers when the efficiency of the riveted joint is known?

31. Give and explain the A.S.M.E. BOILER CODE formula for computing the maximum allowable working pressures for power boilers.

PROBLEMS ON DIVISION 6

1. A cylindrical boiler is 20 ft. long and has inside diameter of 4 ft. What is the total transverse force on the boiler when steam pressure is 125 lb. per sq. in.?

2. The total transverse force tending to rupture a boiler is 1,152,000 lb. If the boiler is 24 ft. long and steam pressure is 120 lb. per sq. in. what is the internal diameter?

3. When a boiler drum is 40 ft. long and 42 in. in diameter, what total stress will be imposed on a longitudinal seam when the steam pressure is 90 lb. per sq in.?

4. If the steel plate in Prob. 1 is 3/8 in. thick, what will be the safe total transverse force in pounds when a factor of safety of 5 is allowed and steel has a strength of 54,000 lb. per sq. in.?

5. A boiler has a steel sheet 1/4 in. thick and is 3 ft. across inside. If the steel has a strength of 45,000 lb. per sq. in. and a safety factor of 4.5 is desired, what is the safe transverse pressure when the seam is neglected?

6. Find the total longitudinal force in a boiler shell when the internal diameter is 21 in. and steam pressure is 150 lb. per sq. in.

7. What is the safe longitudinal resisting strength of a tank 21 in. in diameter, 5/16 in. thick when the ultimate tensile strength of the plate is 50,000 lb. per sq. in. and a factor of safety of 5 is assumed?

8. What is the safe internal pressure with reference to roundabout rupture for the boiler of Prob. 7 when seams are neglected?

9. If the boiler of Prob. 8 is of homogeneous material of a uniform thickness with no seams, what will be the safe pressure with reference to longitudinal rupture?

10. A seamless hollow sphere is made of steel 1/8 in. thick having a strength of 45,000 lb. per sq. in. If it is 15 in. in diameter and a safety factor of 5 is assumed, what will be the safe internal pressure?

11. What is the safe working steam pressure for a cylindrical boiler having a shell with internal diameter of 36 in., 3/8 in. thick, and a strength of 50,000 lb. per sq. in. if the weakest joint has an efficiency of 80 per cent. and a factor of safety of 5 is assumed?

12. What should be the thickness of the boiler shell of Prob. 11 if the pressure is to be 200 lb. per sq. in.?

DIVISION 7

RIVETED JOINTS

208. Rivets Are Used For Fastening Together The Edges Of The Plates Used For Making Boilers So That The Resulting Pressure Vessels May Be Steam-tight.—Attempts have been made to construct such vessels by welding the joints. Thus far, the results have been neither wholly satisfactory nor dependable.

209. Either Iron Or Steel Rivets May Be Used (Table 131).—The tension test (A.S.M.E. Code) for finished steel rivets should be made on a specimen of such length that the elonga-

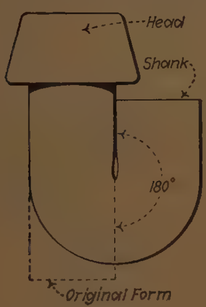


Fig. 156.—Bend-test of a steel or iron rivet.

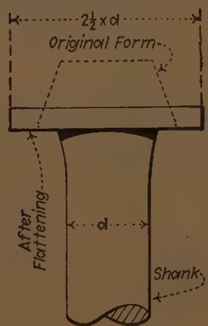


Fig. 157.—Flattening test for steel rivet head.

tions may be measured on a gage length of not less than four times the diameter of the rivet. Both iron and steel rivets should endure, without cracking on the outside, being bent upon themselves (Fig. 156) through 180 deg. The head of a steel rivet should endure without cracking the edges (Fig. 157), being flattened to 2½ times the diameter, *d*, of the shank. The heads of iron rivets should withstand being bent back (Fig. 158), thus showing that they are joined firmly to the shank.

210. The Riveted Joint Is, Usually, The Weakest Element Of The Pressure Vessel.—Hence it is important that the relative strength or *efficiency* be known. The efficiency of a joint is the ratio, expressed as a percentage, of *the strength of the riveted joint to the strength of the solid boiler plate.* The strength of a riveted joint varies with the form of joint. It usually ranges from about 55 to 95 per cent. of that of the plate which is riveted.

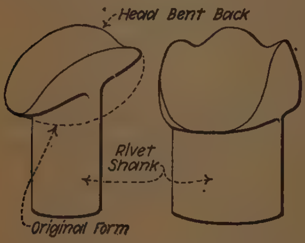


FIG. 158.—Iron rivets with heads bent back without cracking.

EXAMPLE.—See following Table 237 for values of the efficiencies of joints of the different types.

211. Rivet heads of acceptable forms are shown in Fig. 159 which is from the A.S.M.E. CODE. The head of a rivet should be so proportioned that the strength against shearing off of the rim is as great, or greater, than the tensile strength of the shank.

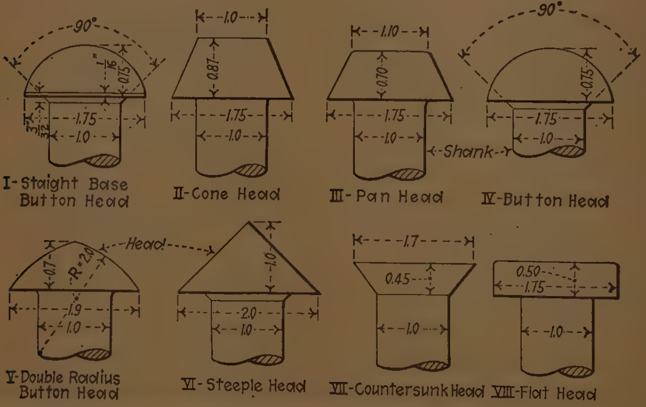


FIG. 159.—Acceptable forms of rivet heads (A.S.M.E. Code, p. 71).

212. The Holes For Rivets May Be: (1) Punched; (2) Drilled; (3) Drilled And Reamed; (4) Punched And Drilled.—If the hole is punched, the material is, especially in thick plate, crushed around the hole and is thereby injured. This injured material may and should be removed subsequently

by reaming or drilling the hole. It is advisable to punch the rivet holes smaller than required and to then, after the plates have been assembled, ream them to size. Thereby it may be insured that the resulting reamed holes in the two or three plates are exactly in line.

NOTE.—The following is from the A.S.M.E. CODE, par. 253: "All rivet holes, staybolt holes and holes in braces and lugs, shall be drilled full size or they may be punched not to exceed 1/4 in. less than full diameter for material over 5/16 in. in thickness and 1/8 in. less than full diameter for material not exceeding 5/16 in. in thickness and then drilled or reamed to full diameter. Plates, butt straps, braces, heads and lugs shall be firmly bolted in position by tack bolts for drilling or reaming all rivet holes in boiler plates, except those used for tack bolts." If the method just specified is followed, there will then be no stresses set up in the joint. Such stresses are liable to occur when the holes are forced into line by using drift pins or by similar methods.

213. "Rivets shall be of sufficient length to completely fill the rivet holes (Fig. 160) and form heads at least equal in

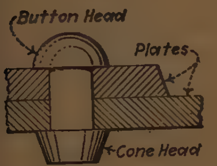


FIG. 160.—Rivet completely fills hole after proper riveting.

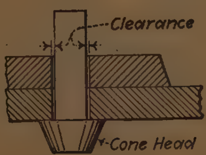


FIG. 161.—Rivet before riveting.

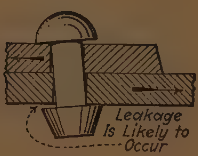


FIG. 162.—Rivet does not fill hole and is not driven tightly.

strength to the bodies of the rivets" (A.S.M.E. CODE, par. 255) If the rivet is not upset sufficiently to fill the hole a very weak joint will, probably, be the result. Steam and water (Figs. 161 and 162) may leak out around such a rivet.

214. Rivets shall be machine driven wherever possible, with sufficient pressure to fill the rivet holes and shall be allowed to cool and shrink under pressure" (A.S.M.E. CODE, par. 256). There are three methods of driving rivets; (1) *By hand;* (2) *With a pneumatic hammer;* (3) *By machine.* The latter method is the best because, with it, the work is uniform and no injury is caused to the surrounding plate.

When riveted with a pneumatic hammer, and especially when riveted by hand, the rivet head is often eccentric.

NOTE.—The riveting machine presses the rivet into form and thus holds it for a short time interval, allowing it to cool and contract. The force may be from 25 to 150 tons, depending on the size of the rivet which is being driven.

215. "The calking edges of plates, butt straps and heads shall be beveled to an angle not sharper than 70 deg. (Fig.

FIG. 163.—The calking edge is beveled.

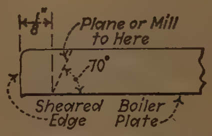


FIG. 164.—Sheared edge of boiler plate should be cut off.

163) to the plane of the plate, and as near thereto (to 70 deg.) as practicable. Every portion of the sheared surfaces of the calking edges of plates, butt straps and heads shall be planed, milled or chipped (Fig. 164) to a depth of not less than ⅛ in. When the plate is sheared, the metal along its sheared edge is crushed and distorted. Stresses are set up therein. By planing or otherwise cutting off the sheared edge, the metal

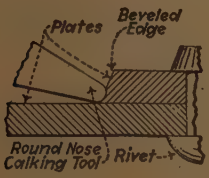


FIG. 165.—No injury to lower plate from round nose calking tool.

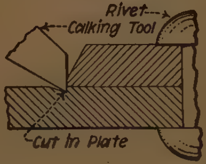


FIG. 166.—Injury from sharp calking tool.

thus injured is removed. Calking (Fig. 165) shall be done with a round-nosed tool" (A.S.M.E. CODE, par. 257). If a sharp-cornered calking tool (Fig. 166) is used, the lower plate may be scored or cut, thus rendering it weaker. Calking is usually on the outside of the vessel.

216. The object of the beveling is to permit the calking to be done more readily. When beveled, the lower edge may, so experience has shown, be turned down with less difficulty.

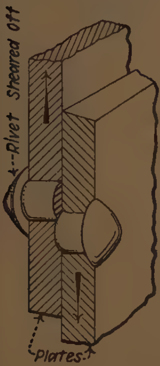


FIG. 167.—Failure due to shearing of rivets.

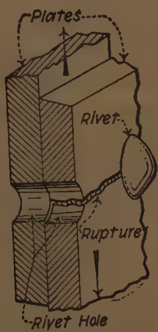


FIG. 168.—Failure due to rupture of plate.

FIG. 169.—Failure due to crushing of plate.

217. The six possible modes of failure of a riveted joint are: (1) *The rivets may shear*, Fig. 167. (2) *The plate may rupture between the rivets*, Fig. 168, due to a tensile stress. (3) *The plate or the rivet may crush*, Fig. 169. (4) *The plate may shear*

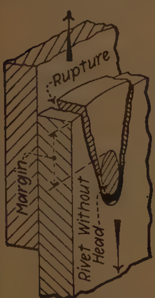


FIG. 170.—Failure due to plate shearing out.

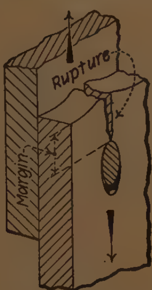


FIG. 171.—Failure due to plate tearing in front of rivet.

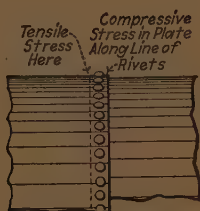


FIG. 172.—Initial stresses in girth seam.

out in front of the rivet, Fig. 170. (5) *The plate may tear in front of the rivet*, Fig. 171. (6) *The failure may be due to a combination of any two or more of the preceding modes.* Figs.

172 and 173 show how the tensile and compressive stresses, which tend to cause failure of riveted joints of a boiler, are produced.

218. Riveted joints may be so designed that failure by any one of the six modes above specified can not occur under normal conditions. For example, the margin may be provided of sufficient width to prevent the tearing (Fig. 171) or the shearing (Fig. 170) of the metal in front of the rivet. In checking a joint for strength, it is unnecessary to consider combinations of failures.

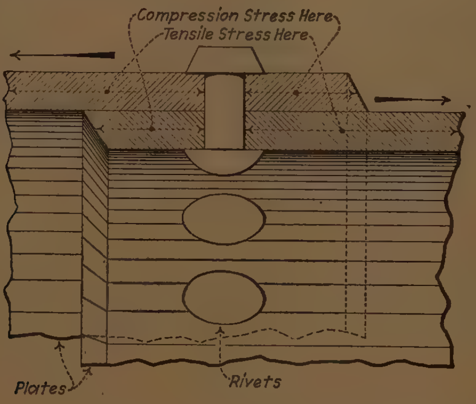


Fig. 173.—Enlarged view showing stresses in seam.

Note.—Experience has shown that if a joint is sufficiently strong to withstand failure by *Modes* (1), (2) and (3), it will also, if designed as directed in Secs. 219 and 220, withstand failure by (4) and (5). Hence, in the practical design and checking for strength of riveted joints, only *Modes of Failure* (1), (2) and (3) need be considered. In following Sec. 236, it is shown how the load which will cause failure by *Modes* (1), (2) or (3) can be determined.

219. Proportions of "back pitch" for riveted joints, which will provide a rational design are specified in the A.S.M.E. Code, par. 182, and are quoted below. These proportions are such that a joint designed in accordance with them will not fail by shearing of the plate (Fig. 170), splitting of the plate in front of the rivet (Fig. 171) or by rupture of the plates between rivets (Fig. 168). Quoting: "The distance between two center lines of any two adjacent rows of rivets, or the

'back pitch' measured at right angles to the direction of the joint shall have the following minimum values:"

(*a*) If P/D is 4 or less:

(53) *Minimum Back Pitch* = 2D (inches)

(*b*) If P/D is over 4, then:

(54) *Minimum Back Pitch* $= 2D + 0.1(P - 4D)$ (inches).

Wherein P = pitch of rivets in outer row, *when the rivet in the inner row comes midway between two rivets in the outer row*, in inches. Also, P = pitch of rivets in the outer row less pitch of rivets in the inner row, *when two rivets in the inner row come between two rivets in the outer row*, in inches. (It is here assumed that the joints are of the usual construction wherein the rivets are symmetrically spaced.) D = diameter of the rivet holes, in inches.

EXAMPLE.—See Figs. 174, 175, 176 and 177.

220. "On longitudinal joints, the distance from the centers of rivet holes to the edges of the plates, except holes in the

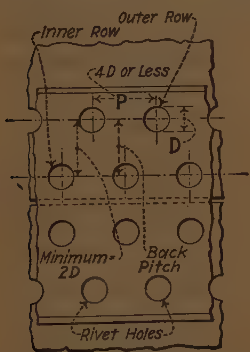


FIG. 174.—Back spacing of rows of rivets when P/D equal 4 or less. (Rivet in the inner row comes midway between two rivets in the outer row.)

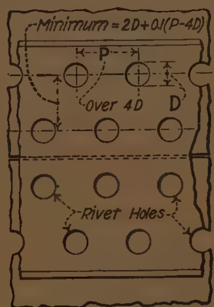


FIG. 175.—Spacing of rivets when P/D is greater than 4. (Rivet in the inner row comes midway between two rivets in the outer row.)

ends of butt straps, shall be not less than 1½ and not more than 1¾ times the diameter of the rivet holes" (A.S.M.E. CODE, par. 183). Fig. 178 shows the manner of measurement. These proportions insure that the metal in the margin

will not, under normal conditions, fail by splitting or shearing out.

221. "The strength of circumferential joints of boilers, the heads of which are not stayed by tubes or through braces, shall be at least 50 per cent. of that required for the longitudi-

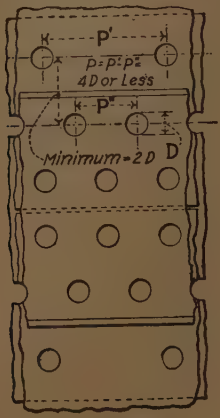


FIG. 176.—Spacing of rows of rivets when P/D equal 4 or less. (Two rivets in the inner row come between two rivets in the outer row.)

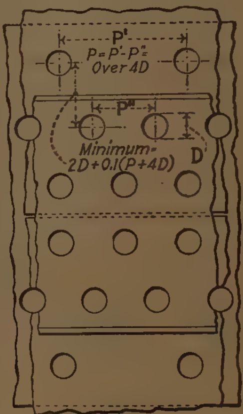


FIG. 177.—Spacing of rivets when P/D is greater than 4. (Two rivets in the inner row come between two rivets in the outer row.)

nal joints of the same structure" (A.S.M.E. CODE, par. 184*a*) The strength of the longitudinal joint should be determined by the load, due to the pressure expected in the boiler, which it must withstand. A weaker circumferential than longitudinal joint is permissable due to the fact that the force tending to rupture the boiler along the circumferential joint is one-half of that tending to rupture it along the longitudinal joint (Sec. 202).

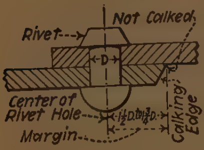


FIG. 178.—Margin of riveted joint.

222. The determination of the required strength of the circumferential joint at a head, when tubes acting as stays support it, may be made thus: "When 50 per cent. or more of the load which would act on an unstayed solid head of the same diameter of the shell, is relieved by the effect of tubes or through stays, then in consequence of the reduction of the

area acted on by the pressure and the holding power of the tubes and stays, the strength of the circumferential joints in the shell shall be at least 35 per cent. of that required for the longitudinal joints" (A.S.M.E. CODE, par. 184b).

EXPLANATION.—In Fig. 179 the area on which steam experts pressure—the area which is stippled in the illustration—is, obviously less than area on which steam would press if there were no tubes. Not alone do the tubes *A* to *C*, decrease the pressure-bearing area, but in addition they assume a portion of the internal longitudinal, thrust against the head, which is due to the contained steam. They assume this thrust because they are headed or riveted over as shown. Thereby the tubes relieve the head of a part of the force which would otherwise be imposed on the outer shell through the circumferential joints. Tubes, when riveted over as shown, brace the heads in about the same manner as do stays.

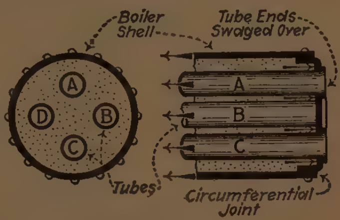


FIG. 179.—Tubes decrease stress in outer shell.

223. When the rivets in a circumferential joint are exposed to the products of combustion, as in a horizontal return tubular boiler, the shearing strength of the rivets shall not be less than 50 per cent. of the full strength of the plate corresponding to its thickness at the joint (A.S.M.E. CODE, par., 184c). This provision is to insure that each rivet will be safe, even though it becomes very hot due to poor conduction of heat away from its center. To satisfy the above requirement, the rivets must have a comparatively small pitch. Hence, the expanding of the outer lap of the joint (Fig. 180) will be minimized. This tends to prevent leaks caused by bulging.

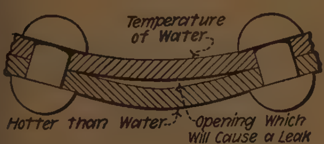


FIG. 180.—Leakage in fire seam when pitch of rivets is too large and allows bulging.

224. When the boiler plate is so thick that it is subject to overheating at a circumferential fire seam, it should be planed or milled down as shown in Fig. 181. This applies to horizontal return tubular boilers which have plates exceeding $9/16$ in. in thickness. If this cut-

ting away of the plate should cause the joint to be weaker than specified elsewhere, then it should be left thicker at the joint (A.S.M.E. Code, par. 185).

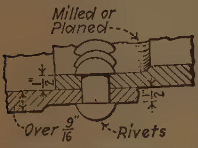


Fig. 181.—Circumferential fire joint for thick plates.

225. Longitudinal Joints May Be Of Lap-riveted Construction If The Boiler Or Drum Is Not Over 36 In. In Diameter And The Steam Pressure Does Not Exceed 100 Lb. Per Sq. In.—If the diameter is greater than 36 in., or the pressure is over 100 lb. per sq. in., the joint should be of butt-and-double-strap construction (A.S.M.E. Code, pars. 187 and 188). The butt joint is the stronger and more dependable, hence this specification.

226. The longitudinal joints of horizontal return tubular boilers should be located above the fire line of the setting (A.S.M.E. Code, par. 189). When subjected to high temperature and the consequent overheating, the failure of the joint is probable. Hence, for safety, all joints should be so located that they will not be exposed to excessive heat.

227. "In Horizontal Return Tubular Boilers With Lap Joints, No Course Shall Be Over 12 Ft. Long.—With butt-and-double-strap construction, longitudinal joints of any length may be used, if the steel-plate test specimens are taken lengthwise of the greatest stress, and the other standard tests are satisfied (A.S.M.E. Code, par. 190). The Massachusetts Rules prohibit *any* seam of a length exceeding 12 ft.

Note.—This restriction is thought to be due to the fact that few, if any, steel mills are prepared for rolling perfect plates wider than 12 ft. Hence if seams longer than 12 ft. are used, it is possible that the fibers of the plate would be lengthwise of the boiler, which is undesirable. Steel plate is not as strong across the fiber as it is along the fiber.

228. "Butt straps and the ends of shell plates which form the longitudinal joints shall be rolled or formed by pressure, not by blows, to the proper curvature" (A.S.M.E. Code, par. 191). If the ends of the plate are brought together as shown in Fig. 182 and then hammered into position, the material may be injured.

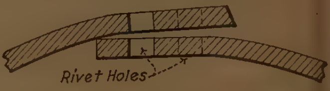


Fig. 182.—Lapped ends of plate as ring comes from rollers.

229. A unit strip of a riveted joint is the shortest length, along the joint that divides the rivets symmetrically. It is a strip with width equal to the maximum pitch (Figs. 183, 184, 185, 186, 187 and 188). When the imaginary center lines, which thus divide a joint into unit sections, pass through a rivet, only one-half of the rivet is considered in the calculation.

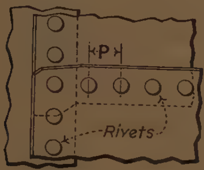


FIG. 183.—Lap joint, single riveted.

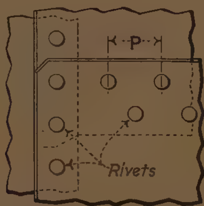


FIG. 184.—Lap joint, double riveted, staggered.

NOTE.—In computing the strength of a practical boiler joint, the strength for the entire sheet could be estimated. But such procedure would be tedious because of the unnecessarily-large number of figures involved in the calculation. The same information concerning the relative strength of the joint may be obtained by considering *any* length of the joint which divides the rivets symmetrically. Hence, the "unit strip" is used to conserve time and effort.

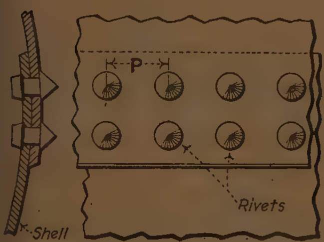


FIG. 185.—Lap joint, double riveted (chain).

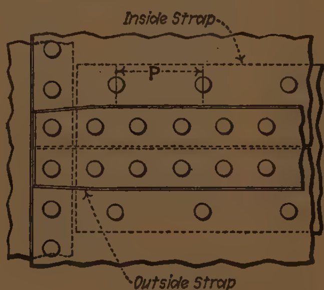


FIG. 186.—Butt joint, double riveted.

230. To compute the tensile strength of a unit strip of solid boiler plate, *multiply together the length of the unit section in inches, the thickness of the plate in inches, and the tensile strength of the material in pounds per square inch.* Or, stating the rule as a formula:

(55) $$S_T = L_U L_t S_T \quad \text{(pounds).}$$

Wherein: S_T = tensile strength of the unit strip, in pounds. L_U = width of the assumed unit strip, in inches. L_t = thickness of the plate, in inches. S_T = unit tensile strength of the material, in pounds per square inch.

EXAMPLE.—See under HOW TO COMPUTE THE EFFICIENCY OF A RIVETED JOINT, Sec. 236.

231. To compute the tensile strength of the plate between the rivet holes (Fig. 168): *Subtract the diameter of the rivet hole from the width of the unit strip, in inches. Then multiply*

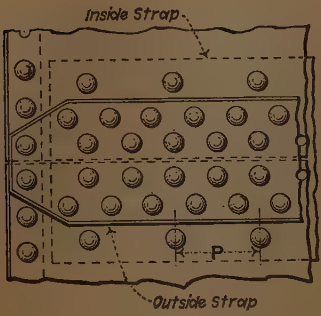


FIG. 187.—Butt joint, triple riveted.

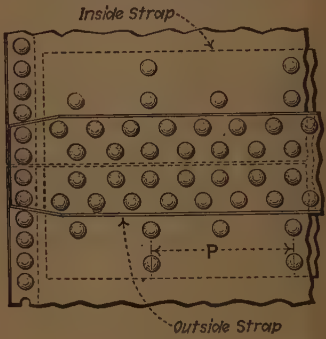


FIG. 188.—Butt joint, quadruple riveted.

together the value thus obtained, the thickness of the plate and the tensile strength of the material in pounds per square inch. Stating these operations as a formula:

(56) $$S'_T = (L_U - d)L_tS_T \qquad \text{(pounds)}.$$

Wherein: S'_T = tensile strength of plate between rivet holes, in pounds. d = diameter of rivet holes, in inches. The other symbols have the same meanings as specified for the preceding formula.

EXAMPLE.—See under HOW TO COMPUTE THE EFFICIENCY OF A RIVETED JOINT, Sec. 236.

232. To compute the shearing strength of the rivets in a unit strip, *multiply together the area, in square inches, of one rivet to be sheared, the number of rivets, and the shearing*

strength, in pounds per square inch, of the rivet material. Expressed as a formula:

(57) $$\mathbf{S}_s = NAS_s \quad \text{(pounds).}$$

The above formula will give the *single-shear* (Fig. 167) strength. The *double-shear* (Fig. 189) strength of a rivet may be taken as twice its single-shear strength.

Wherein: $\mathbf{S}_s$ = shearing strength of the rivets in single shear, in pounds. $\mathbf{N}$ = number of rivets in unit strip. A = cross-sectional area in square inches, of one rivet after driving. S_s = unit shearing strength of the rivet material, in pounds per square inch.

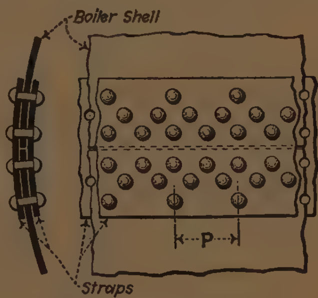


FIG. 189.—Butt joint, triple riveted, straps equal width.

EXAMPLE.—See under HOW TO COMPUTE THE EFFICIENCY OF A RIVETED JOINT, Sec. 236.

233. To compute the crushing strength of the plate in front of the rivets or of the rivets themselves (Fig. 169), *multiply together the number of rivets, the diameter of one rivet in inches, the thickness of the plate in inches, and the crushing strength of the plate material in pounds per square inch.* Expressed as a formula:

(58) $$\mathbf{S}_c = \mathbf{N}dL_tS_c \quad \text{(pounds).}$$

Wherein: $\mathbf{S}_c$ = crushing strength of the rivet or plate, in pounds. S_c = the unit crushing strength of the plate material, in pounds per square inch. The other symbols have the same meanings as specified above.

EXAMPLE.—See under HOW TO COMPUTE THE EFFICIENCY OF A RIVETED JOINT, Sec. 236.

234. The efficiency of a riveted joint is the ratio, expressed as a percentage, of the strength of a unit length of a riveted joint to the strength of the same unit length of the solid plate. It is the percentage strength of the joint as compared with the strength of the plate.

235. The process in determining the efficiency of a riveted joint is to calculate the resisting strength of the joint against failure by: MODE 1, *Rivets Shearing;* MODE 2, *Plate Rupturing Between Rivets;* MODE 3, *Plate or Rivet Crushing.* The weakest mode of failure is taken as the maximum strength of the joint. Then, the maximum strength thus determined is divided by the strength of the plate to find the efficiency. The determination of efficiency for a simple joint is illustrated in the following example. The process as applied to joints of the various types is given in detail in the A.S.M.E. CODE.

236. How to compute the efficiency of a riveted joint may be understood from a study of the following example.

EXAMPLE.—A single-riveted lap joint (Fig. 183) of $\frac{7}{16}$ in. plate has $\frac{7}{8}$ in. rivets with a pitch of 2 in. Tensile strength of plate material is 55,000 lb. Shearing strength of rivet material is 44,000 lb. per sq. in. Crushing strength of plate material is 95,000 lb. per sq. in. What is the efficiency of the joint? SOLUTION.—Assume a 2-inch unit strip. The tensile strength of the solid plate, Formula (55) = $S_T = L_U L_t S_t$ = = $2 \times \frac{7}{16} \times 55{,}000 = 48{,}125$ lb. The tensile strength of the plate between rivet holes, Formula (56) = $S'_T - (L_U - d) L_t S_t = (2 - \frac{7}{8}) \frac{7}{16} \times 55{,}000 = 27{,}070$ *lb.* The cross-sectional area of a $\frac{7}{8}$ *in.* rivet is 0.601 in. The shearing strength of one unit in single shear, Formula (57) = $S_s = NAS_s = 1 \times 0.601 \times 44{,}000 = 26{,}444$ *lb.* The crushing strength of the plate in front of one rivet is Formula (58) = $S_c = NdL_tS_c = 1 \times \frac{7}{8} \times \frac{7}{16} \times 95{,}000 = 36{,}367$. Obviously, the joint is weakest in shear. Hence, the efficiency of the joint = $E = S_s/S_t = 26{,}444 \div 48{,}125 = 0.55$ = 55 *per cent.*

FIG. 190.—Butt joint, quadruple-riveted, saw tooth type.

237. Table. The efficiencies of the various joints vary with the strength of the material that is used in the plate and rivets and with the design of the joint. The following are conservative values for well-designed joints of good materials.

Type of joint	Fig. No.	Efficiency, per cent.
Single-riveted, lap joint	183	55
Double-riveted, lap joint	184,185	70
Triple-riveted, lap joint	....	75
Single-riveted, butt joint	....	65
Double-riveted, butt joint	186	80
Triple-riveted, butt joint	187	85
Quadruple-riveted	188	90
Triple-riveted, straps equal width	189	83
Quadruple-riveted, straps saw-tooth	190	93

NOTE.—The above table lists values for the most-commonly-used joints. It does not include all joints which may be used. An actual joint may, under test, show efficiencies higher or lower than those quoted, depending upon materials, workmanship and other variables. Typical joints are shown in Figs. 183 to 190 inclusive. For a complete treatment of the subject of riveted joints, see DESIGN OF STEAM BOILERS AND PRESSURE VESSELS by Haven and Swett.

QUESTIONS ON DIVISION 7

1. For what is a riveted joint used?
2. Of what material are rivets made?
3. What are the tests for rivets?
4. What part of a pressure vessel is weakest?
5. What is meant by the efficiency of a riveted joint?
6. How should the holes be made and be prepared for rivets? Why?
7. Why should a rivet fill the hole after being driven?
8. What are the three methods of driving rivets? Which method is the best?
9. Describe the calking edge of a plate?
10. Discuss the six modes of failure of a riveted joint.
11. Is it possible to eliminate the probability of failure by any of these modes of failure? How?
12. What are the formulas for determining the minimum back pitch?
13. Why is the distance from the edge of the plate, in longitudinal joints, to the center of the rivet specified? What is the specification?
14. What should be the strength of the circumferential joint as compared to the longitudinal joint of a boiler?
15. How is the calculation for the circumferential joint at the head of a drum calculated when tubes act as stays?
16. When a boiler plate is over $\frac{9}{16}$ in. thick, or so thick that it is subject to overheating, at the circumferential joint what should be done?
17. When the boiler drum is not over 36 in. in diameter and the pressure is not to be over 100 lb., what kind of a joint may be used for the longitudinal seam?
18. Why should a seam in a boiler drum not be exposed to the high temperature of the furnace?
19. What is the limit of length of joint allowed by the A.S.M.E. Code in a horizontal return tubular boiler when the joint is of the butt and double-strap construction?

20. How shall the plates that lap to make the longitudinal joint be formed to curvature? Why should they not be hammered to shape?

21. State and explain the formula for computing the strength of a unit strip of solid boiler plate.

22. State and explain the formula used for computing the tensile strength of a riveted unit strip of boiler plate.

23. How is the shearing strength of the rivets in a unit strip determined?

24. State and explain the formula for computing the crushing strength of the plate in a unit strip.

25. How is the maximum strength of a unit strip determined?

26. How is the efficiency of a joint determined?

27. What is the range of the efficiencies of the joints of the various types?

PROBLEMS ON DIVISION 7

1. A double riveted, lap joint (Fig. 184) is riveted with steel rivets $3/4$ in. in diameter. The pitch of the rivets is $2\frac{1}{2}$ in. and the thickness of the plate is $5/16$ in. What is the efficiency of the joint?

DIVISION 8

BRACES AND STAYS

238. The tendency of a pressure within an approximately cylindrical vessel is to force the shell into a truly cylindrical shape and to force the heads into truly hemispherical shape. Hence, any pressure-sustaining boiler surface, which is neither hemispherical nor cylindrical in shape, has forces imposed on it which tend to cause the surface to assume one of those shapes.

239. When a vessel has a flat pressure-confining surface of relatively great area, it is necessary to stay that surface to prevent distortion, and the possible rupture which might occur due to the tendencies described in the paragraph just preceding. Since cylindrical, spherical and hemispherical surfaces are "self-staying" (because of the reasons outlined in Div. 6), they require no bracing.

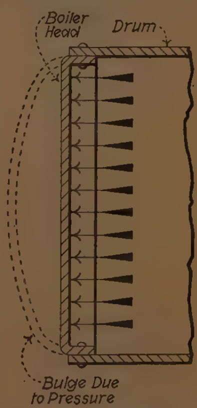


FIG. 191.—Internal pressure tends to bulge head.

EXAMPLE.—If a flat boiler-head (Fig. 191) is subjected to a high internal pressure, its tendency is to assume the bulged shape indicated by the dashed outline. To prevent the plate from assuming the bulged shape and, possibly, from rupturing, stays or braces must be used to hold it.

240. Boiler Stays Should Satisfy Three Requirements.—(1) *The stays should be of sufficient number and strength that they will—assuming that the plate itself has no strength nor stiffness—wholly support the plate.* (2) *The stays should be so disposed that they will offer minimum interference to inspection of the boiler.* (3) *The stays should be so arranged they will offer minimum obstruction to the circulation of water in the boiler.*

241. Boiler Stays May Be Divided Into Three General Classes.—(1) *Through Stays.* (2) *Diagonal stays.* (3) *Gusset*

Stays. Each is treated in following Secs. Through stays are not desirable for spans exceeding 20 ft. in length. If used for longer spans, they will sag in the middle and not assume the total load imposed on the end plates.

NOTE.—In general, through stays are preferable, structurally, to diagonal stays. Sometimes it is necessary to apply either through or diagonal stays to provide a construction which will not interfere with the inspection of the interior of the boiler. Gusset stays usually interfere materially with inspection and impede water circulation. Hence they are now seldom used in America.

242. The Procedure In Designing The Staying For A Flat Surface Is.—(1) *Compute the force of the pressure against the surface which is to be stayed.* (2) *Space and design the stays so that they will safely support this force.* When tubes pass through a plate they will support part of the surface.

243. How to design the staying for the end plate of a horizontal return-tubular boiler (Fig. 192), in accordance with

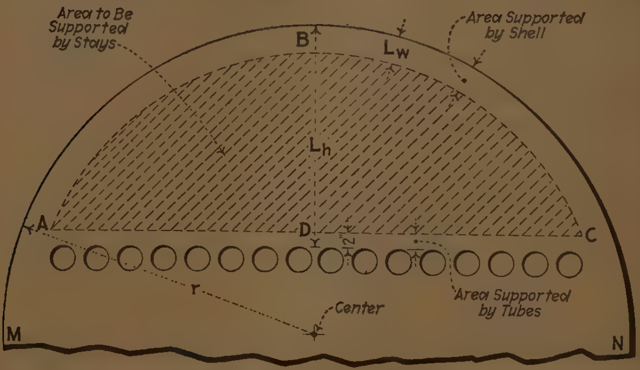


FIG. 192.—Determining net area of segment of boiler head for staying. (A.S.M.E. Code p. 56).

A.S.M.E. CODE requirements, will now be explained: It is assumed that the tubes support the lower part, *ACNM*, of the sheet and that the shell supports a strip, *ABC*, of the width L_w, which is determined thus:

$$L_w = \frac{5L_t}{\sqrt{P}} \qquad \text{(59)} \quad \text{(inches.)}$$

Wherein: L_w = width of the strip which may be assumed to

be supported by the boiler shell, in inches. L_t = thickness of the plate in the head, in *sixteenths of an inch*. P = maximum allowable pressure in pounds per square inch.

It is assumed the 2-in.-wide area. ADC, above a line just outside of the tubes, is supported by the tubes. Now, the area of the segment, $ABCD$, which remains to be stayed, should be determined. This area may be ascertained directly from tables, which will be found in various engineer's handbooks. Or it may be computed by applying For. (60) given in the following Sec. The area of the segment having been determined, and the maximum allowable steam pressure being known, the total force which will be exerted against the segment is found by multiplying *the steam pressure per square inch* by *the number of square inches in the segment.* The spacing of the stays is now then ascertained by applying For. (62) given in a following Sec. It is now only necessary to compute a value for the diameter of the stays. This should be such that when the stays jointly assume the total force imposed on the segment, the allowable stress in them will not be exceeded.

244. To compute the area of a segment of a circle the following formula (see Fig. 192) may be used:

$$(60)\quad A = \frac{4(L_h - L_w - 2)^2}{3}\sqrt{\frac{2(r - L_w)}{(L_h - L_w - 2)} - 0.608} \quad \text{(area, sq. in.)}.$$

Wherein: A = the area of the segment to be stayed, in sq. in. r = the radius, (Fig. 192) of the shell, in inches. L_h and L_w are the distances, in inches, as shown in Fig. 192.

245. Diagonal Stays Must Be Designed To Assume Greater Tension Than Corresponding Stays Perpendicular To The Stayed Surface.—If the stays are through stays perpendicular to the surface to be supported (Fig. 193), the total resistance offered by the stays should be equal to the total pressure imposed on the segment to be supported. But if they are diagonal stays (Fig. 194) the cross-sectional area of each may be calculated by applying this formula:

$$(61)\quad A_d = \frac{A_t L_d}{L_p} \quad \text{(square inches)}.$$

Wherein: A_d = the cross-sectional area of the diagonal stay, in square inches. A_t = the cross-sectional area of a through stay of the same metal, which would safely support the load, in square inches. L_d = length of the diagonal stay, in inches. L_P = distance from the surface supported to the center of the palm of the diagonal stay, in inches.

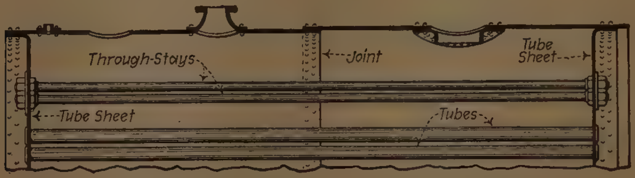


FIG. 193.—Through stays in a Scotch boiler.

EXPLANATION.—For (61) follows from the law of the resolution of forces. If line AO (Fig. 195) be drawn proportional in length to the stress in the through stay, then line BO will be proportional in length to the stress in the corresponding diagonal stay. Hence, $A_d : L_d :: A_t : L_P$ therefore, $A_d = A_t L_d / L_P$

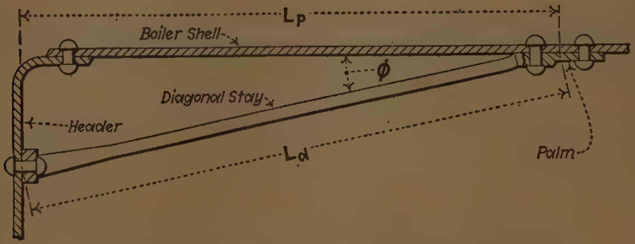


FIG. 194.—Stress in diagonal stay (A.S.M.E. Code, p. 61).

246. The formula for computing the proper spacing of stays in flat plates is given in Par. 199 of the A.S.M.E. CODE:

(62) $$L_p = L_t\sqrt{C \div P} \quad \text{(inches)};$$

Wherein: L_p = distance (Fig. 196) between stay centers, or the pitch, in inches. L_t = thickness of the stayed plate, in *sixteenths* of an inch. C = a constant, values for which are given in the following table. P = maximum allowable working pressure in pounds per square inch. For usual conditions the pitch of the stays, as determined by the formula, will be from 5 in. to 7 in.

EXAMPLE.—Assuming that, for given conditions, a 6-in. pitch is found to provide the proper spacing. Then, each stay (Fig. 196) supports: 6 × 6 = 36 *sq. in.* of surface. If the pressure is to be 150 lb. per sq. in., then a through stay should be of such diameter that it will safely sustain a load of; 36 × 150 = 5,400 *lb.* Strictly, the cross-sectional area of the stay should be deducted from the unit area to be supported, before figuring the load to be sustained.

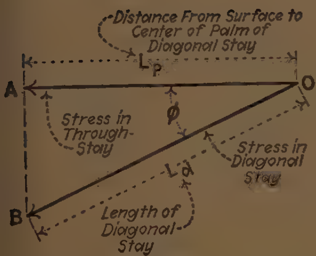


FIG. 195.—Illustrating the derivation of the diagonal-stay formula.

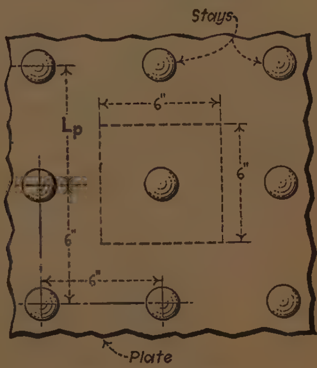


FIG. 196.—Stay supports area 6 × 6 in.

247. Table showing values of "C" for the stay-spacing formula.

Condition	Value of C
Stays screwed through plates not over 7/16 in. thick and riveted	112
Stays screwed through plates over 7/16 in. thick and riveted	120
Stays screwed through plates and fitted with nuts outside	135
Stays fitted with heads not less than 1.3 times the diameter the stays, screwed through the plates or made a taper fit and having the heads formed on the stays before installing them and not riveted over, said heads being made to have a true bearing on the plate	150
Stays fitted with inside and outside nuts and outside washers where the diameter of the washers is not less than 0.4 L_p and the thickness not less than L_t	175

248. Table showing maximum stresses allowable in stays and staybolts.

Because of the excessive stresses and corrosion to which staybolts may be subjected, the allowable stresses which are specified by the A.S.M.E. Boiler Code (par. 220*c*) and which are here tabulated, are very low. Stay bolts may be of either iron or steel.

Class	Description of stays	Allowable stresses, lb. per sq. in.	
		For lengths between supports not exceeding 120 diameters	For lengths between supports exceeding 120 diameters
a	Unwelded or flexible stays less than 20 diameters long, screwed through plates, with ends riveted over..................	7,500	.....
b	Hollow steel stays less than 20 diameters long, screwed through plates, with ends riveted over....	8,000	....
c	Unwelded stays and unwelded portions of welded stays, except as specified in line *a* and line *b*.....................	9,500	8,500
d	Steel through stays exceeding 1½″ diameters	10,400	9,000
e	Welded portions of stays	6,000	6,000

249. Through stays are stay-rods which connect one end of the boiler with the other (Fig. 193), thus supporting both end plates so that they will not bulge. The ends of the stays may be fastened to the plates as shown in Fig. 197. Such stays are shown in this book in Figs. 47, 48 and 50.

250. Diagonal stays are made in many different forms. Figure 198 illustrates typical designs. Installations are shown in Figs. 53 and 83. In Fig. 199 is illustrated the *crowfoot diagonal stay*. Another form of fastener for the end of a crowfoot stay is delineated in Fig. 200.

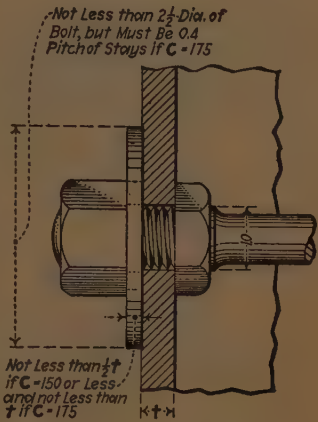


FIG. 197.—Through-stay end.

251. Girder stays (Fig. 201) are used for supporting crown plates or other flat plates which may bound a fire-box. That of Fig. 201 is in one piece. Other types are illustrated in Figs. 48 and 49.

252. Sling stays (Fig. 202) are also used to support crown sheets. A sling stay may extend from the boiler shell to a girder stay as indicated in Fig. 202. Sling stays are shown in Fig. 51.

253. Gusset stays, Fig. 203, perform the same function as do diagonal stays. They are made of flat plate and are much stiffer than the stays of the other types. Hence great care must be exercised in their installation. If improperly set, excessive expansion and contraction stress may result.

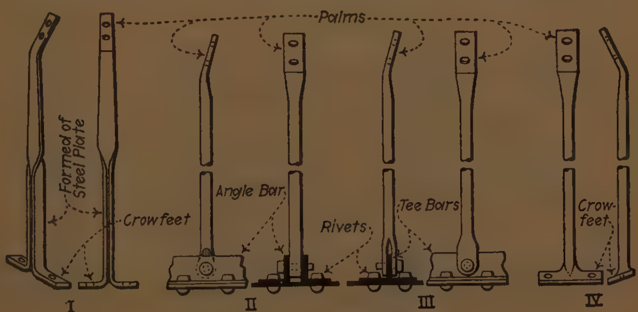


FIG. 198.—Diagonal stays.

254. Stay Bolts Are Short "Through Stays."—They are used in bracing water-leg plates and other flat surfaces which are relatively close together. They are applied most frequently in locomotive and marine-type boilers as shown in Figs. 48

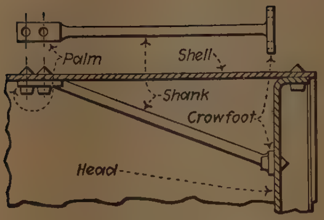


FIG. 199.—Crowfoot stay (riveted feet).

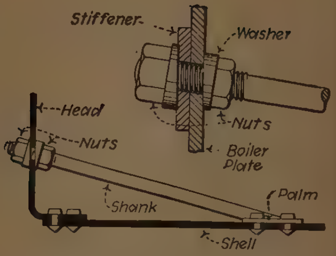


FIG. 200.—Form of fastening for diagonal stays in Scotch boilers.

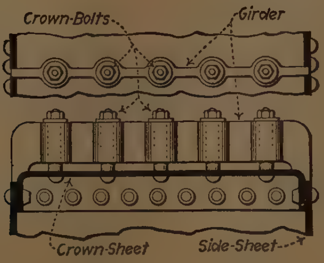


FIG. 201.—One piece girder stay.

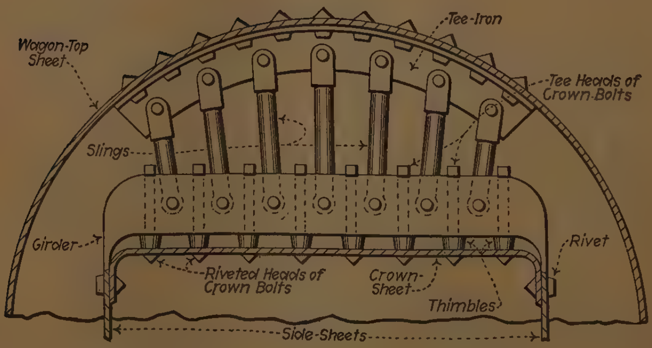


FIG. 202.—Sling stays supporting girder stay.

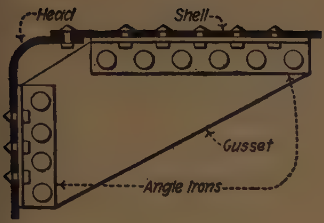


FIG. 203.—Gusset stay.

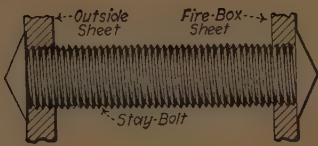


FIG. 204.—Stay bolt.

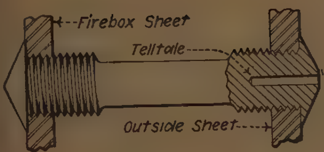


FIG. 205.—Stay bolt with threads cut away.

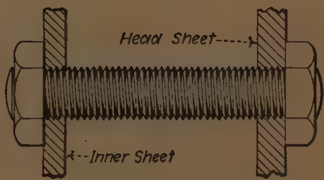


FIG. 206.—Stay bolts with nut.

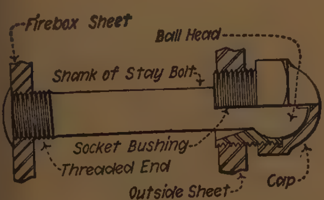


FIG. 207.—Flexible stay bolt.

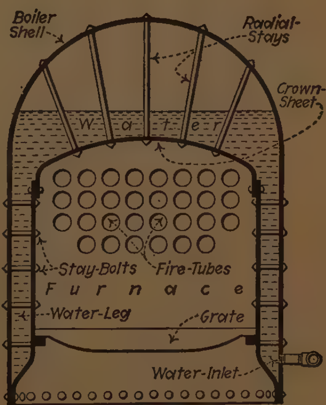


FIG. 208.—Radial stays in a locomotive type boiler.

and 49. Ordinarily, the bolt (Figs. 204 and 205) is threaded, screwed in place and riveted over. In Fig. 205 is shown a bolt which has the threads turned off to minimize corrosion. Corrosion, so experience shows, is exceedingly pronounced at the root of the thread. The end of a stay bolt (Fig. 206) may be secured by nuts. Hollow stay bolts (Fig. 68), which permit the insertion of the nozzle of a soot blower, are sometimes used. Other illustrations of stay bolts are shown in Figs. 54, 56 and 57.

255. Stay Bolts Are Subjected To Bending As Well As To Tensile Stresses.—The bending stresses are due to the un-

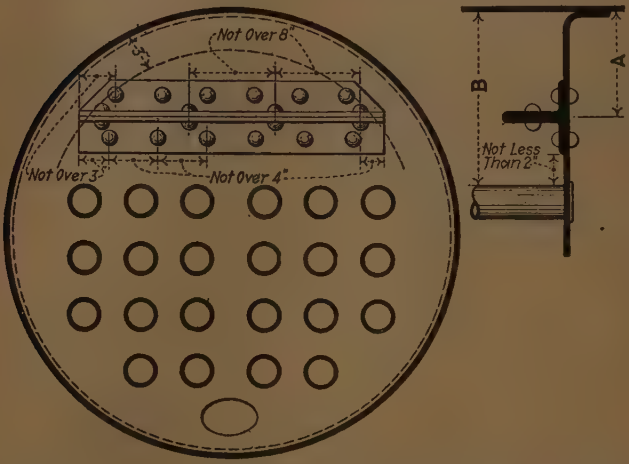


FIG. 209.—Staying of head with steel angles. (A.S.M.E. Code, page 62.)

equal expansion of the plate near the fire and that heated only by the water. This bending stress increases as temperature differences occur. Finally, the bolt may break near the plate without the rupture being apparent from the outside. A hole drilled in the end of the bolt (Fig. 205) permits steam or liquid to escape as soon as the rupture penetrates to the center of the bolt. Thus, an automatic "tell-tale" is provided. To allow for lateral movement and thus minimize bending stresses, flexible stay bolts (Fig. 207) have been designed. They have not been and probably will not be employed gener-

ally because of their high cost, complication and the relatively large space which they occupy.

256. Radial stays (Fig. 208) are employed to stay two plates which have different radii of curvature. They are used principally in locomotive boilers.

257. Steel Angles May Be Used For Staying Tube Sheets (Fig. 209).—The A.S.M.E. Code permits such staying, where the boiler does not exceed 36 in. in diameter and the pressure is not greater than 100 lb. per sq. in. It also specifies the sizes of the angles which may be so used.

QUESTION ON DIVISION 8

1. What is the effect of applying pressure inside of a vessel when it is deformed from a truly cylindrical form?
2. Why is it necessary to stay a flat surface?
3. What three requirements should a boiler stay satisfy?
4. What are the three general classes of stays?
5. What is the procedure for designing stays?
6. How is the width of the strip adjacent to the shell in a horizontal return-tubular boiler, which is assumed to be supported by the shell, determined?
7. State and explain the use of the formula for computing the area of a segment.
8. How is the area of a diagonal stay determined?
9. Give the formula for finding the spacing of stays in flat plates.
10. Why are the allowed stresses in stays much lower than the ordinary safe load for the material?
11. What are through stays? Diagonal stays? Girder stays? Sling stays? Gusset stays?
12. What is a stay bolt? Where are they used?
13. What is the manner of preparing a stay bolt so that it may be known when it cracks due to repeated bending?
14. When are radial stays used?
15. When are steel angles permitted for use for staying a flat plate?

DIVISION 9

FIRE-TUBES AND WATER-TUBES

258. The purpose of fire-tubes and water-tubes in boiler construction is to increase the evaporative efficiencies of the boilers above those which are possible with a plain-cylinder boiler. The introduction of fire-tubes and water-tubes accomplishes this by increasing the value of the ratio the heating area to the volume of the water space.

259. Fire-tubes (Figs. 47, 51 and 56) afford internal passages, within a boiler shell, through which the gases of combustion flow from the combustion chamber (Figs. 47 and 48) or fire-box (Figs. 51 and 57) to the smoke-box. They are surrounded by water.

260. Water-tubes (Figs. 60, 66, 71 and 72) divide the water space of a boiler into a number of sections. The space within each tube constitutes a section. Water circulates through the tubes while the hot gases surround them externally.

261. The most important stress in a water-tube is the transverse stress which tends to rupture the tube longitudinally. This stress is exactly like that which is exerted by the steam pressure directly against the boiler shell (Div. 6.)

262. The stresses in a fire-tube or flue are produced as follows: (1) *By the pressure of the steam, which is transmitted through the mass of water to the surface of the tube or flue.* This produces a transverse crushing stress. (2) *By the pressure of the steam* (Fig. 210) *against the head-sheets or tube-sheets into which the ends of the tube or flue are secured.* This produces a longitudinal tensile stress.

Note.—The tensile stresses in fire-tubes and flues are, ordinarily, very inconsiderable by contrast with the crushing stresses. Fire-tubes and flues perform a subordinate function in staying the sheets (Fig. 210) to which their ends are secured. Failure on account of a pressure acting parallel to the length of a fire-tube, occurs, therefore, by separation of the tube from the sheet rather than by rupture of the tube itself.

263. Failure of a fire-tube or flue under a transverse crushing stress invariably occurs by collapse (Fig. 211) of the wall of the tube or flue. Theoretically, a fire-tube or flue should not fail by application of a uniform pressure against the entire outside area of its wall, until the crushing strength of the tube material is exceeded. This condition would be realized if the tube were ideally cylindrical in contour. But

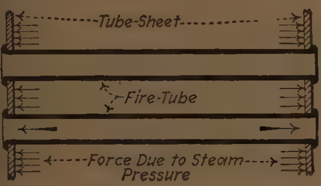


FIG. 210.—Longitudinal stress in fire tube.

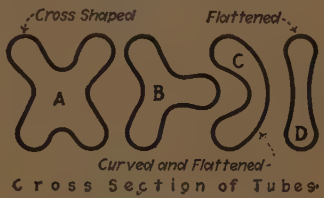


FIG. 211.—Collapse of tubes due to external pressure.

the ideally-perfect cylinder is unattainable in practice. The steam pressure tends constantly to augment any slight irregularity that exists in the tube contour. As the distortion develops, resistance to its further increase progressively diminishes. Consequently, the tube or flue will fail by collapse long before the material becomes stressed to the limit of its compressive strength.

NOTE.—Corrugations in the wall of a flue (Fig. 47) diminish its tendency to collapse under pressure. This is due mainly, to the stiffening effect of the corrugations.

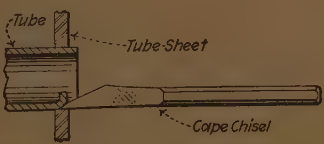


FIG. 212.—Cutting tube with cape-chisel.

FIG. 213.—Tube bent in preparation for removal.

264. The diameters and thicknesses of fire-tubes and water-tubes for various pressures are given in Tables 264*A* and 264*B* below. The greater the diameter and the greater the steam pressure, the greater must be the tube thickness.

11

264A. Table Showing A. S. M. E. Boiler Code Maximum Allowable Working Pressure for Tubes for Water-tube Boilers for Different Diameters and Gages of Tubes

Outside diam. of tube in inches, D	Thickness of tube in Birmingham wire gage and in inches												
	17 $t=0.058$	16 $t=0.065$	15 $t=0.072$	14 $t=0.083$	13 $t=0.095$	12 $t=0.109$	11 $t=0.120$	10 $t=0.134$	9 $t=0.148$	8 $t=0.165$	7 $t=01.80$	6 $t=0.203$	5 $t=0.220$
½	434	686	938	1334									
¾	206	374	542	806	1094								
1	...	218	344	542	758	1010							
1⅛	...	166	278	454	646	870	1046						
1¼	...	124	225	383	557	758	916	1118					
1½	...	...	146	278	422	590	722	390	1058				
1¾	...	...	...	203	326	470	583	727	871	1046			
2	...	...	...	146	254	380	479	605	731	884	1019		
2¼	...	...	...	...	198	310	398	510	622	758	878	1062	
2½	...	...	...	...	153	254	333	434	535	657	765	931	1053
2¾	...	...	...	...	117	208	280	372	464	575	673	824	935
3	...	...	...	...	...	170	236	320	404	506	596	734	836
3¼	...	...	...	...	...	...	199	276	354	448	531	658	752
3½	...	...	...	...	...	...	167	238	310	398	475	594	681
3¾	...	...	...	...	...	...	139	206	273	355	427	537	619
4	...	...	...	...	...	...	...	178	240	317	385	488	565
4½	...	...	...	...	...	...	...	...	186	254	314	406	474
5	...	...	...	...	...	...	...	...	142	204	258	340	402

$$P = \left(\frac{t - 0.039}{D}\right)18000 - 250$$

Where P = Maximum allowable working pressure, lb. per sq. in. t = Thickness of tube wall, in. D = Outside diameter of tube, in.

Note: Maximum Allowable Working Pressures For Superheater Tubes shall be the same as for boiler tubes,

264B. The A.S.M.E. Boiler-Code Minimum Thickness Of Tubes Used In Fire-Tube Boilers measured by Birmingham wire gage, for maximum allowable working pressures not exceeding 175 lb. per sq. in., shall be as follows:

Diameter	Thickness	
	Inches	B.W.G.
1 in. or over, but less than 2½ in.	0.095	No. 13
2½ in. or over, but less than 3¼ in.	0.109	No. 12
3¼ in. or over, but less than 4 in.	0.120	No. 11
4 in. or over, but less than 5 in.	0.134	No. 10
5 in.	0.148	No. 9

NOTE.—For each increase of one gage in thickness above that shown in the table, the maximum allowable working pressure will be increased by 200 lb. divided by the diameter of the tube in inches.

265. Defective fire- or water-tubes may be removed from a boiler by one of the following operations: (1) *By cutting a lengthwise slot in each end of the defective tube with a cape chisel* (Fig. 212) *and then battering in* (Fig. 213) *the metal adjacent to the edges of the slot.* The tube can then be drawn out through the tube-hole in the sheet which is located most conveniently for the manipulation. This method is applicable for water-tubes, or where the end of a fire-tube has not been upset with a beading-tool. (2) *By first cutting off, with a flat chisel, the beaded end of the tube flush with the tube sheet, and then slotting and battering in the end as explained above.* (3) *By cutting off the end of the tube just inside the sheet.* This requires the use of a special cutting-tool.

266. The procedure of replacing a fire- or water-tube in a boiler is as follows:

(1) *The tube-holes should be examined to determine their condition. If found nicked, or otherwise damaged, they should be turned up with a reamer. If the edges of the tube-holes are sharp, they should be blunted with a half-round file. The new tube should now be placed in position, with its ends pro-*

jecting through the sheets from 0.25 *in. to* 0.5 *in.* (Par. 252, A.S.M.E. BOILER CODE).

(2) *If a water-tube is being replaced, the ends should preferably be made steam-tight with a Prosser expander* (Fig. 214). *With this tool an annular rib or bulge is rolled out in the wall*

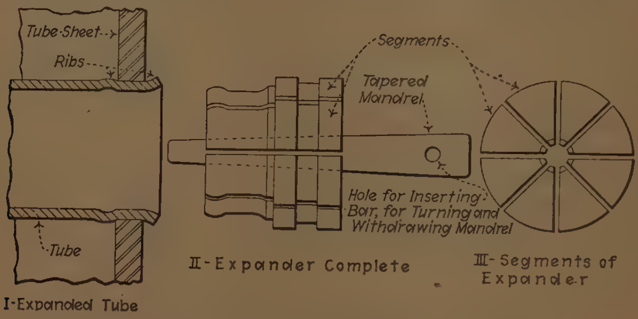


FIG. 214.—Prosser method of expanding water-tube end.

of the tube, both inside and outside the tube-sheet. Very often the tube-hole will be found somewhat larger in diameter than the tube. In such cases it is necessary to line up the hole. The liners are preferably made of strips of charcoal wrought iron. But in the absence of wrought iron, soft sheet steel may be used.

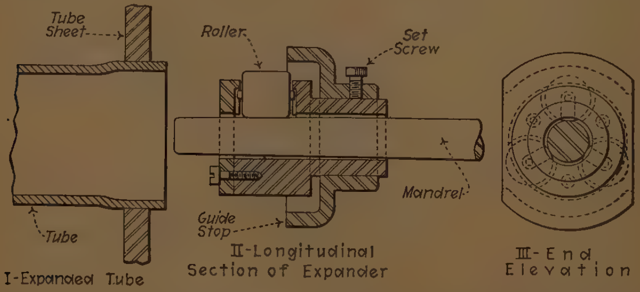


FIG. 215.—Method of expanding fire-tube end. (The outside diameter of the end of the tube illustrated at *I* above is intentionally shown distorted. This diameter remains practically the diameter of the remainder of the tube unless the tube hole is oversize.)

(3) *If a fire-tube is being replaced, the ends may be made secure with either a Prosser or a Dudgeon expander* (Fig. 215). *With this tool only the portion of the tube within the hole is*

rolled out. If damage to a tube-hole has necessitated its enlargement by reaming, the end of the tube may be correspondingly enlarged by brazing on a *copper ferrule* (Fig. 217). The wall of the tube is expanded to a steam-tight fit in the hole. Coincidentally, the projection of the tube outside the tube-sheet is flared or belled out. The ends are now beaded over (Fig. 216). The dotted lines (Fig. 216) show the position of the beading tool when the work of turning the bead is begun. As the work progresses, the beading tool is gradually brought to the position indicated by the full lines.

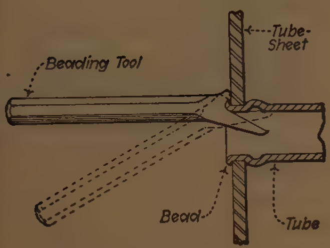


FIG. 216.—Beading tool.

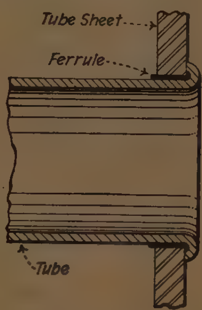


FIG. 217.—Tube with ferrule.

NOTE.—The A.S.M.E. BOILER CODE, Par. 250, requires that a fire-tube boiler shall have both ends of the tubes substantially rolled and beaded. Or, otherwise, the tubes may be rolled and beaded at the smoke-box end and rolled and welded at the combustion chamber or fire-box end. Projecting tube-ends are prohibited for tbe reason that the heat of combustion will burn off such projections.

NOTE.—The A.S.M.E. BOILER CODE, Par. 251, requires that the ends of all tubes, suspension-tubes and nipples in water-tube boilers and super-heaters shall be flared not less than 0.125 in. over the diameter of the tube-hole. Or, otherwise, the tube may be flared not less than 0.125 in., and then rolled and beaded or rolled and welded.

267. Water-Tubes May Be Secured With Threaded Ends (Fig. 218).—This mode of attachment is, however, limited to special forms of construction wherein structural difficulties render the ordinary expanded joint practically impossible. The primary furnace-tubes of a Hawley down-draft furnace (A Kewanee down-draft furnace is shown in Fig. 451) are

an example. In this construction one end of each tube makes a screwed joint with the front drum-sheet while the other end makes an ordinary expanded joint with the rear drum-sheet.

NOTE.—In former years, fire-tubes which make a threaded joint with a tube-sheet were common. The threaded connection to the sheet was often reinforced with a thin nut (Fig. 219). Fire-tubes connected in

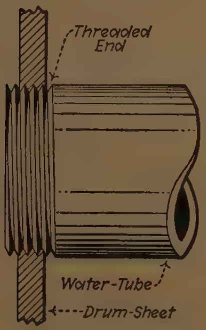


FIG. 218.—Threaded connection of water-tube in down-draft furnace.

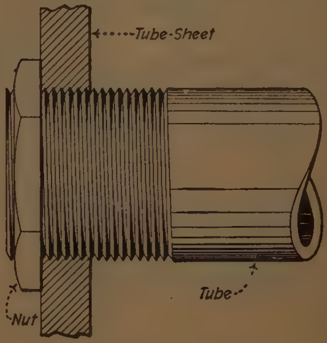


FIG. 219.—Stay tube.

this manner are called *stay-tubes*. They are now rarely used except in large Scotch boilers. Ordinarily, they are impracticable. This is on account of the necessity of exposing the extra bulk of metal in the nut and projecting tube-end directly to the heat of the furnace gases.

QUESTIONS ON DIVISION 9

1. What is the chief advantage of the tubular form of construction in steam boilers?
2. State the distinction between fire-tubes and water-tubes.
3. What is the principle stress in water-tubes.
4. What stresses must fire-tubes withstand?
5. Why do failures of fire-tubes occur by collapse of the wall of the tube rather than by simultaneous crushing of the material at all points?
6. In what manner do corrugations strengthen a flue?
7. How are defective tubes removed from a boiler. How replaced?
8. How should the ends of a water-tube be secured?
9. What is the purpose of the copper ferrules on the ends of a fire-tube?
10. What are the requirements of the A.S.M.E. BOILER CODE with respect to the ends of fire-tubes and water-tubes?
11. What is a stay-tube?
12. What is the chief objection to stay-tubes?

DIVISION 10

MANHOLES AND HANDHOLES

268. Manholes and handholes are necessary openings in steam boilers. They are essential in the building, repairing and inspection of such pressure vessels.

269. Manholes afford access of a man to the boiler interior. In manufacture, it is necessary in certain riveting operations that a helper be inside of the boiler. When inspecting, the boiler inspector must examine the interior of the shell. This, where the space in the boiler is sufficiently large, he can do more effectively by entering the shell than by merely looking at it through a small hole. Also, it is necessary for a man to enter the shells of the larger boilers for the removal of scale formations. The A.S.M.E. CODE specifies certain provisions for manholes, which are abstracted in succeeding Secs.

270. Handholes are provided in small boilers and in the larger boilers, when the tube arrangement is such that it would be impossible for a man to enter the boiler. These handholes are sufficiently large to accommodate a man's hand. They are used in repairing, and in inspection, when it is necessary to see inside, and for removing and inserting tubes and other parts.

271. The proper number of and locations for manholes, handholes and washout holes in a steam boiler are specified in Pars. 264 to 267 of the A.S.M.E. CODE. These "access" holes should always be so located that they will permit of proper inspection, cleaning, and repairing and yet not affect materially the strength of the boiler structure. The holes should be in positions where highly-heated gases will not contact with them.

272. The size of a manhole should be such as will permit an average-sized man to pass easily through it. The size and shape of a manhole may, particularly in the smaller boilers, be of various designs. Generally, however, elliptical openings are provided. Openings of other forms may be necessary due to a certain arrangement of tubes or other parts.

NOTE.—The A.S.M.E. CODE (Par. 258) provides that the minimum allowable dimensions for an elliptical manhole are, in the clear, an 11-in. minor diameter and a 15-in. major diameter, or it may be 10 × 16 in. When the manhole is circular it should be not less than 15 in. in diameter.

273. Either Wrought Steel, Wrought Iron Or Cast Steel Shoud Be Used In Manhole Construction.—These materials

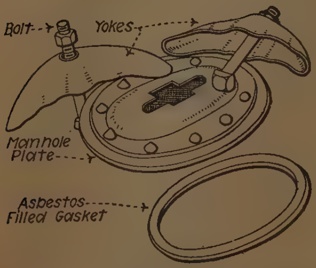


FIG. 220.—Details of forged-steel manhole cover.

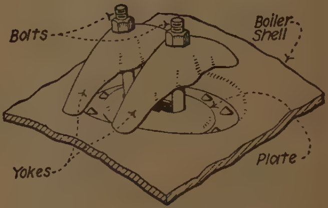


FIG. 221.—Manhole plate in position.

are much stronger and more reliable than the cast iron which was, formerly, widely employed. Covers or "plates" (Fig. 220) are now of wrought or cast steel. Steel yokes and bolts (Fig. 221) hold the cover in place in the manhole. Gaskets (Fig. 220), which are discussed further in a succeeding Sec., are always necessary under the covers. The yokes—either one or two may be used—are placed parallel to the minor axis.

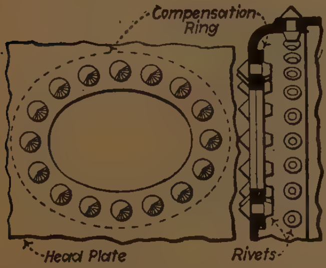


FIG. 222.—Flat strengthening ring.

274. Every manhole opening must be reinforced to compensate for the metal which has been cut away in making the hole. If not thus reinforced, the boiler shell will not have sufficient strength in the vicinity of the hole. A reinforcing method which was formerly used for both head (Fig. 222) and shell manholes involved the riveting on of plain *compensation rings*. These were usually attached on the outside of the shell, but were often placed inside.

NOTE.—Reinforcing or compensation rings were formerly of cast iron. But this metal, because of its inherent weakness and brittleness, was relatively ineffective. Its use for such service is now prohibited by boiler codes.

275. Modern practice in reinforcing holes in heads is to flange over (Fig. 223) the manhole edges. Since the head plate is stiffened by the flange, the making of a manhole in this manner does not materially weaken the head.

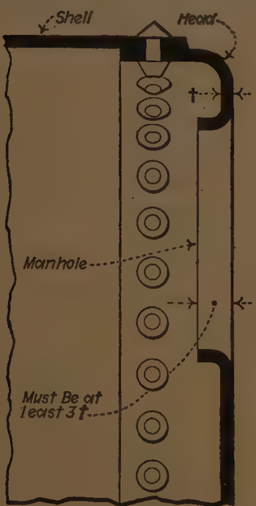


FIG. 223.—Manhole with flanged edges.

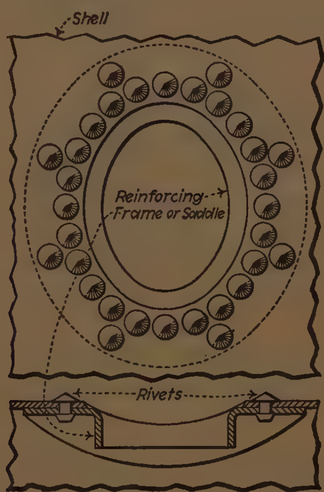


FIG. 224.—Reinforcing frame or saddle.

276. In reinforcing manhole openings in drums and shells (Fig. 224), flanged frames or saddles are employed. These are riveted to the shell plates. When the shell diameter exceeds 48 in., they are double riveted. Such saddles are stamped from hot flat plate. Their proportions may be determined by the method described in the following Sec.

277. The strength of manhole frames and reinforcing rings must be at least as great as the tensile strength of the maximum amount of shell removed by the opening and rivet holes for the reinforcement on any line, through the manhole or other opening parallel to the longitudinal axis of the shell; so specifies the A.S.M.E. CODE. To understand what this

means, assume that the frame or ring is of the same material as the boiler shell. Then, the net longitudinal cross-sectional area of the frame or reinforcing ring must at least equal the longitudinal cross-sectional area of the metal which was removed from the shell in making the manhole. The metal removed is represented by the "manhole opening" and the rivet holes.

EXAMPLE.—In Fig. 225 is shown a sectional view on a line parallel to the longitudinal axis of the boiler. Then, the total tensile strength of metal sections $A + C + D + F$ must be equal to or greater than the total tensile strength of sections $X + Z + Y$.

278. The Shearing Strength Of The Rivets On Each Side Of The Axis Of The Manhole Frame Parallel To The Longitudinal Axis Of The Boiler, Should Be At Least As Great As The Tensile Strength Of The Metal Removed As Manhole Opening And Rivet Holes On That Axis (A.S.M.E. CODE).—This means (referring to Fig. 226) that the shearing strength of all of the rivets on the right of $A–A$ should be at least equal to the tensile strength of the material removed from the boiler shell along $A–A$. Manhole frames for manholes in boiler shells exceeding 48 in. in diameter should be riveted to the shell or drum, with two rows of rivets arranged as shown in Fig. 226.

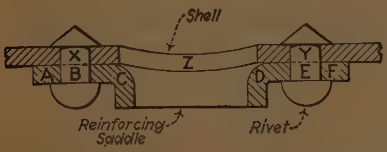


FIG. 225.—Section, through reinforced manhole in boiler shell, on outer line parallel to the longitudinal axis of the shell.

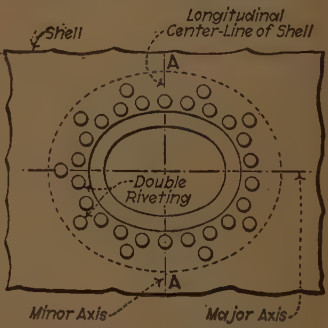


FIG. 226.—Minor axis of manhole should, preferably, be parallel to longitudinal axis of shell.

279. Gaskets must be used around manholes to prevent leakage. The gasket seat must be so designed as to prevent the gasket from being blown out by the steam pressure. The gasket should be of a material which will withstand both heat

and dampness. Rubber or asbestos compositions are used. Corrugated copper rings are also employed. See Fig. 227 for details of a manhole and cover assembly.

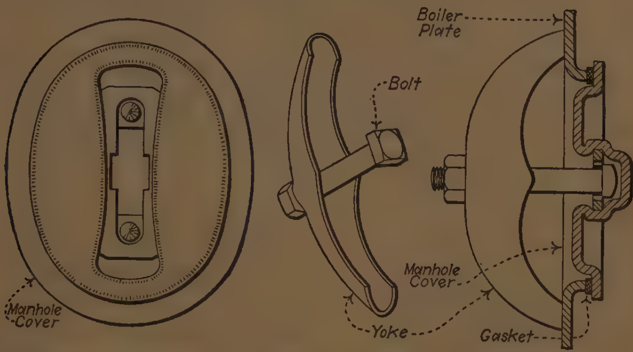


FIG. 227.—Pressed-steel manhole cover and assembly to boiler plate.

280. The Width Of Bearing Surface For A Manhole Gasket Should Be Not Less Than ½ In.—In small boilers the plate may be so thin that a ½-in.-wide surface will not be provided by the edge of the metal. In such cases the bearing surface may be increased as necessary by shrinking a forged iron or steel band (Fig. 228) on the inner flange. Where it is necessary that the band provide strength to reinforce the manhole opening, it may be made so that it extends (Fig. 229) back on the shell plate. It is riveted in position.

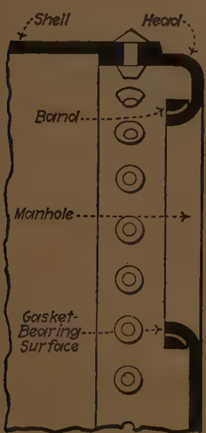


FIG. 228.—Band around flanged manhole in flat head.

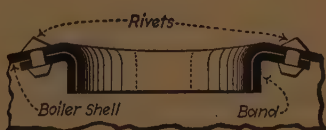


FIG. 229.—Band riveted around flanged manhole in bumped head.

281. The construction of handholes and handhole plates is similar to that for manholes. Reinforcing rings are not used.

The usual form for handholes is elliptical. The average dimensions are about 3 in. by 4½ in. When located in water-legs and headers, round and odd-shaped handholes are often used. Handholes, as provided in boilers for inspection and other purposes, are shown in Figs. 50, 56 and 62.

282. A round handhole is often used in water-legs when the tubes are perpendicular to the leg, as shown in Fig. 230. In Fig. 231 is shown an assembly of a round handhole plate and parts in a water-leg. See also Fig. 67.

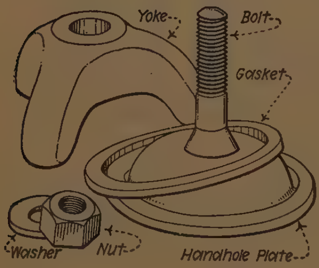


FIG. 230.—Round handhole cover and parts.

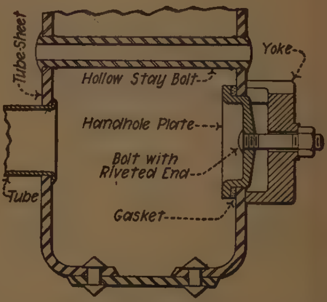


FIG. 231.—Handhole in leg of Murray Iron Works water tube boiler.

283. Handholes May Be Closed By Inside Or Outside Covers.—Figs. 64 and 65 illustrate the difference in application. When the cover is outside, the bolt must assume all of the force of the steam pressure on the plate.

EXAMPLE.—A 5-in.-diameter, circular handhole plate is held in place by a bolt. When the internal steam pressure is 200 lb. per sq. in., what load due thereto must the bolt sustain to hold the plate in place. SOLUTION.—*Total force* = *(area in sq. in.)* × *(boiler pressure in lb. per sq. in.)* $= F = AP_B = 5^2 \times 0.785 \times 200 = 3927$ *lb.*

284. Plates Of Elliptical or Elongated Handholes May Be Removed Through Their Own Openings.—In Fig. 232 is illustrated a plate which is used in headers where the tube intersects the header at an oblique angle. This plate may be removed from within the opening which it covers. In boilers where the shape of handholes and their covers is such that the cover can not be removed through the hole, then the covers

must be removed through a larger handhole at some other location in the boiler or water-leg.

285. A Handhole Cap May Be Used Now In Lieu of A Handhole Plate.—The *Key Handhole Cap* (See Div. 3 of this book, Figs. 68 and 69) has of late been used extensively. Where this cap is employed, no other part is necessary. The circular handhole opening is machined to a taper to fit the cap, which has the same taper. When forced into place and rolled inside of the cap with a special rolling device to insure a tight fit, the steam pressure holds it in place. No gaskets are necessary. To remove the key cap, it is struck on its outside edge a few blows with a hammer. The cap then is lowered with a tool and chain into lower part of the water-leg. From thence it may be removed through a special handhole.

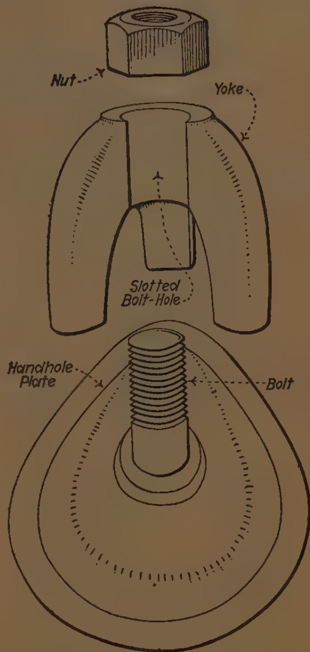


FIG. 232.—Handhole plate used in union water-tube boiler.

QUESTIONS ON DIVISION 10

1. For what are handholes and manholes used?
2. In general, where should manholes and handholes be located?
3. What is the minimum size of a manhole?
4. Of what material should manhole parts be made? Why not cast iron?
5. Why and how much should a manhole be reinforced?
6. What is the method of strengthening the opening in a boiler-drum head?
7. How is the size of the reinforcing ring for a manhole determined?
8. What is the specification for the shearing strength of rivets with which a reinforcing ring is fastened?
9. Why are gaskets necessary? Of what may they be made?
10. What is the minimum width of the bearing surface for a gasket?
11. In general, what may be said concerning the construction of handhole openings?
12. How are handhole plates or covers attached?
13. How are handhole covers removed from water legs when they are attached on the inside?
14. How is the Key handhole cap used?

DIVISION 11

BOILER ACCESSORIES

286. Boiler accessories may be defined as appliances, fittings or mountings which are either intimately connected with the boiler structure or with the work of boiler operation and maintenance. They are indispensable to safety, economy and convenience.

NOTE.—This Division deals with the most intimately connected accessories and appliances. See author's POWER-PLANT AUXILIARIES AND ACCESSORIES for other power-plant equipment.

287. A safety-valve is a device for relieving the pressure in a boiler, or other closed vessel, by allowing the enclosed

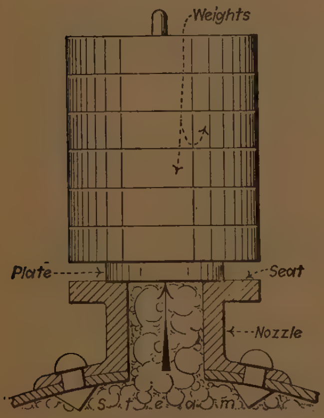


FIG. 233.—Elementary form of safety valve with flat-seated valve.

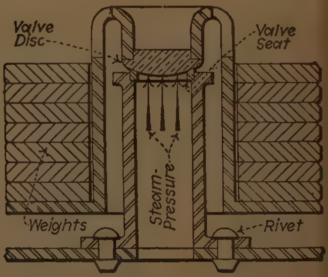


FIG. 234.—Coburn type of dead weight safety valve.

fluid to escape when the pressure becomes greater than desired. Fig. 233 shows a simple, but impracticable, arrangement which would allow the steam to escape if the pressure in the boiler became great enough to push the plate from its seat.

NOTE.—The safety valve is an insurance against explosion from overpressure.

288. There are three types of safety valves, as follows: (1) *Dead-weight safety-valves* (Fig. 234). (2) *Weighted-lever safety-valves* (Fig. 235). (3) *Spring-loaded safety-valves* (Fig. 236).

289. The operation of the dead-weight safety-valve is obvious from Fig. 234. This type of valve has long been virtually obsolete in America largely on account of its bulkiness and inconvenience of adjustment. Its accessibility for improper adjustment by the unauthorized is another decided disadvantage.

290. The operation of the Ball-And-Lever safety-valve (Fig. 235) is similar to that of the dead-weight valve. The force of the weight *W*, is, however, applied indirectly. The weight is placed on a lever, which, in turn, applies downward pressure on the valve disc. Other conditions being equal, a smaller weight is required than in the case of the dead-weight valve. This is due to the leverage.

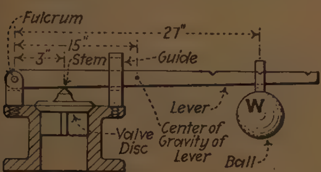


Fig. 235.—Simple form of ball-and-lever safety valve.

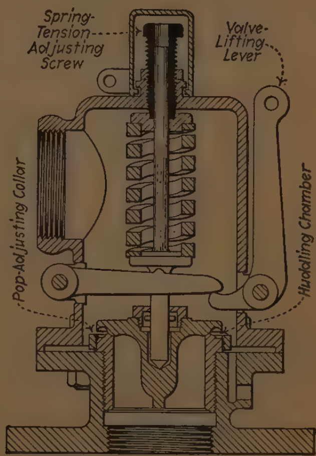


Fig. 236.—Spring-loaded safety valve.

291. The formula for solving problems relating to the blowing pressures of weighted-lever safety-valves (Fig. 237) is:

$$(63) \qquad P_B = \frac{W_W L_W + W_L L_L + W_D L_D}{A L_D} \qquad \text{(pressure, lb. per sq. in.)}$$

Wherein P_B = steam pressure, in lb. per sq. in. W_W, W_L, and W_D = weights of ball, lever, and valve disc and stem, in pounds. L_W, L_L, and L_D = horizontal distances from fulcrum of lever to the center of gravity of the ball, of the lever (Fig.

238), and of the valve disc, in inches. A = area of valve disc exposed to steam when the valve is closed, in square inches.

NOTE.—If the weights of the lever and valve disc and stem are neglected, the formula becomes:

$$P_B = \frac{W_M L_W}{A L_D} \qquad \text{(pressure, lb. per sq. in.)} \tag{64}$$

Wherein the values of the symbols are the same as in For. (63).

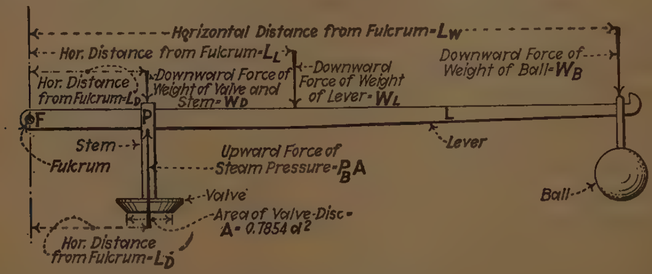


FIG. 237.—Diagramatic explanation of operating principle of ball-and-lever safety valve.

EXAMPLE.—In Fig. 235 the ball weighs 45 lb., the area of the valve is 5 sq. in., the ball is 27 in., and the valve stem is 3 in., from the fulcrum. Neglect the weights of the lever, valve disc and stem. At what pressure will the valve leave its seat? SOLUTION.—Substituting in the formula $P_B = (W_W L_W) \div (A L_D) = (45 \times 27) \div (5 \times 3) = 81$ *lb. per sq. in.*

292. The spring-loaded safety-valve (Fig. 236) is more reliable than those of other types. The valve disc is held on its seat by a spring which is usually enclosed and which will not get out of adjustment readily. Spring-loaded valves open, for full discharge, with a sudden upward thrust or "pop." For this reason they are commonly called *pop safety valves.*

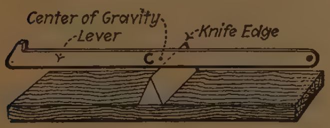


FIG. 238.—Method of finding center of gravity of safety-valve lever

293. The Closing Force Of A Safety Valve Spring Increases As The Valve Disc Is Lifted From The Valve Seat.—The more a spring is compressed, the greater is the force of its resistance to further compression. The closing force of a weighted safety-valve does not increase as the valve is opened.

EXPLANATION.—A spring-loaded valve with an ordinary flat or bevel-eated disc would be practically useless as a safety-valve. When the team pressure increased sufficiently to lift the disc against the tension f the spring, a slight opening would occur and a small quantity of steam vould escape. The disc would continue to rise in response to a constant ncrease of pressure. But the closing force of the spring would be con-tantly augmenting. Consequently, the valve might not give sufficient pening for escape of the steam as fast as the steam would be generated. The pressure might then increase to 20 to 40 pounds greater than the nitial opening pressure. Therefore, safety-valve seats must be speci-lly designed, as will be shown.

294. The design of a spring-loaded safety-valve should be uch that the disc will lift instantly to a maximum height

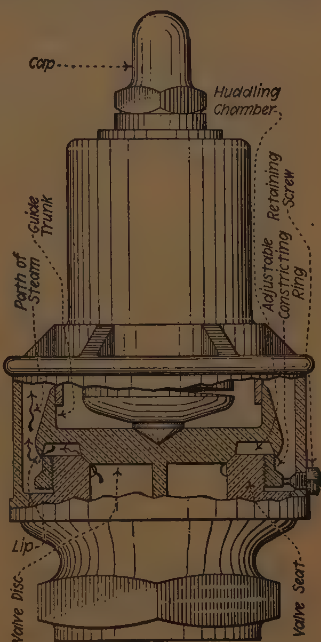


FIG. 239.—Spring-loaded safety valve with threaded constricting ring.

vhen the steam has attained the ressure for which the valve is et. This is accomplished (Fig. 39) by increasing the area gainst which the steam acts, nd hence the opening force, imultaneously with the first light opening of the valve. The surfaces which enclose the ath of the escaping steam are o arranged as to utilize the re-ctionary force of the steam for ifting the valve disc.

EXPLANATION.—When the steam ressure against the exposed surface f the valve disc (Fig. 239) is sufficient o cause the disc to rise from its seat small quantity of steam escapes hrough the very small opening be-ween the disc and seat. This steam mpinges against the top surface f the huddling chamber and is de-lected downward. It strikes the ottom surface of the huddling cham-er. Thence it passes out through he restricted opening between the lip of the disc and the adjusting ring. This restriction causes a pressure to develop in the huddling chamber. This is in addition to the force exerted by the fast-moving steam particles vhich are escaping through the opening between the disc and seat. Thus, the upward pressure against the disc is greatly augmented. The

valve spring is compressed accordingly. A sudden, wide, opening of the valve results.

295. The loss of pressure between the popping pressure of a spring-loaded safety-valve and the closing pressure is called the *blow-back* or *blow-down*. Means are provided for raising and lowering the adjusting ring (Fig. 239) which will increase or decrease the blow-back. The blow-back usually allowed varies from about 3 to 8 lb. per sq. in.

296. A method for raising and lowering the adjusting ring of a spring-loaded safety-valve is shown in Fig. 240. By means of the adjusting screws, *s*, the ring may be raised and lowered, thus opening or restricting the passage for steam from the huddling chamber.

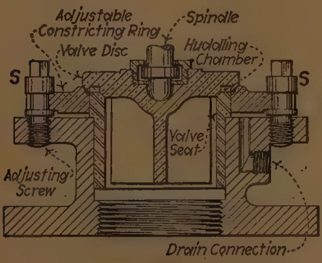


FIG. 240.—Details of a spring-loaded safety-valve disc and constricting ring. (American Steam Gage & Valve Mfg. Co.)

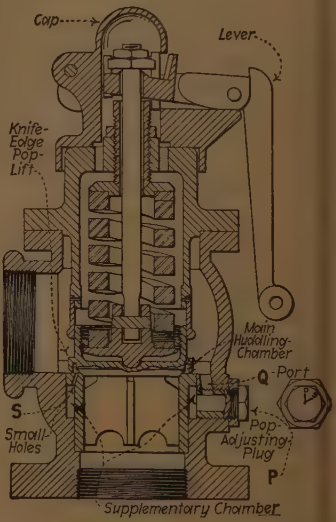


FIG. 241.—Ashton spring-loaded safety valve.

297. A pop safety-valve with, "main" and "supplemental" pop chambers is shown in Fig. 241. These chambers are connected by a series of small holes, *s*. The back pressure in the main chamber is controlled by the pressure in the supplemental chamber. The pressure in the supplemental chamber is controlled by means of the pop-adjusting plug, *p*. A slight rotation of the plug in either direction increases or decreases the area of opening through the port, *Q*.

298. A pop safety-valve with an auxiliary spring is shown in Fig. 242. This valve has also an auxiliary disc *A*. The

huddling chamber is practically steam tight when the valve is closed. Immediately the main disc *M*, lets a small quantity of steam under the auxiliary disc, *A*, the pressure beneath, *A*, rises. The auxiliary spring, *S*, compresses more easily than does the main spring, *T*. Hence, the auxiliary disc lifts immediately and opens the auxiliary ports. The added pressure

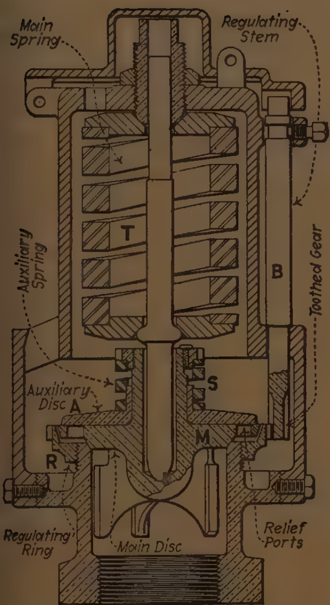


FIG. 242.—Crane spring-loaded safety valve with auxiliary spring.

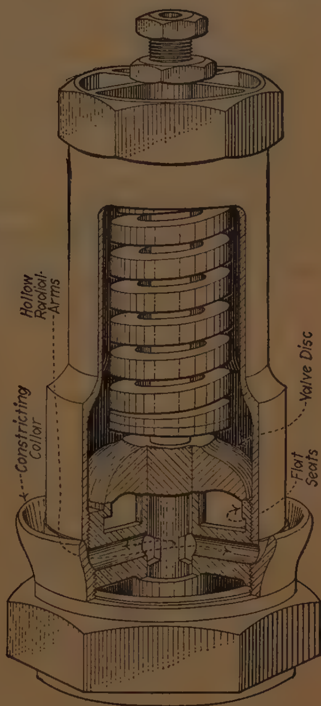


FIG. 243.—Locomotive type of Crosby spring-loaded safety valve.

upward against the auxiliary disc augments the rising tendency of the main disc from the main valve seat. The blow-back adjustment is made by screwing the regulating ring, *R*, up or down by means of the regulating stem *B*. This restricts more or less, the passage of steam from the huddling chamber through the holes in the encasing sleeve.

299. The Seat Of A Safety-valve May Be Either Flat Or Beveled.—The A.S.M.E. CODE requires that beveled seats be made to incline at 45 deg. or at some angle between 45 deg. and 90 deg., with the center line of the valve spindle. Fig. 243 illustrates a safety-valve with a flat or 90-deg. seat.

300. The valve seat and valve disc should be of material which will not corrode and so impair the working of the valve. If these parts were of iron they might become rusted together so that the valve would not open as it should. These parts should be made of monel metal, bronze or nickel.

301. For computing the discharge capacity of a safety-valve see the method used in the Appendix of the A.S.M.E. BOILER CODE.

302. Table Showing Comparison Of Lifts, Discharge Areas And Relieving Capacities Of Seven Different Makes Of Pop Safety-valves.—(Diameter of all valves, 4 in.; popping pressure for all, 200 lb. per sq. in. MARK'S HANDBOOK, p. 921.)

Lifts		Effective area of discharge with opening lift, sq. in.	Per cent. of largest opening.	Relieving capacities	
Opening, in.	Closing, in.			Pounds of steam per hour. $W = 105LDP$.	H.p. on basis of 30 lb. evap. per hr. = 1 h.p.
0.064	0.024	0.568	46.6	5,780	193
0.031*	0.017	0.390	31.4	3,960	132
0.056	0.032	0.496	40.8	5,060	169
0.094	0.039	0.834	68.5	8,500	283
0.094	0.055	0.834	68.5	8,500	283
0.082	0.054	0.727	59.7	7,400	247
0.137	0.088	1.220	100.0	12,400	413

* Flat seat; all other valves with 45-deg. seats.

303. Chattering Of Pop Safety-valves Is Generally Due To Incorrect Mounting.—If the safety-valve is installed on the end of a vertical pipe of considerable length, or on an elbow or tee attached to a horizontal pipe (Fig. 244), trouble is

sure to result. This is on account of the frictional resistance of the connections.

EXPLANATION.—The pressure of the steam impinging directly upon the valve is made variable and inconstant by the frictional resistance. The pressure will fall as the valve lifts and then rise again as the valve drops back. This condition is manifested in a violent vibration. It produces a destructive hammering or chattering of the valve on its seat. Chattering may be caused by incorrect design or adjustment.

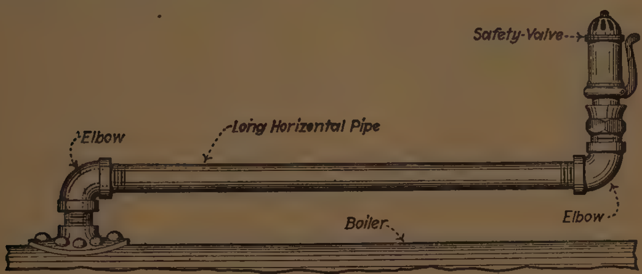


FIG. 244.—Safety valve mounted in long horizontal pipe.

304. When More Than One Safety-valve Is Required For A Boiler, The Valves May Be Mounted On A Single Base.—Fig. 245 illustrates such an arrangement for two valves on a Y base. Fig. 246 shows a duplex valve. (See A. S. M. E. CODE, Par. 276.)

305. The proper installation of a pop safety-valve requires that it be attached to a saddle nozzle (Fig. 245) if possible (CRANE COMPANY CATALOGUE). If piping (Fig. 244) is used between the boiler and the valve, it should be of a larger size than the nominal diameter of the valve. Care should be taken that no chips, scale, red lead or other substances are left in the inlet of the valve, or in the boiler connections to it.

NOTE.—THE FIRST TIME PRESSURE IS RAISED IN A BOILER ON WHICH NEW POP VALVES HAVE BEEN INSTALLED, the valve should be opened by pulling the lever when the pressure is within about 5 or 10 pounds of the set pressure stamped on the valve. The valve should be held open about one minute, or long enough to make sure that all foreign matter has been blown out of the valve and connections. If piping is installed in the outlet of the valve, it should under no circumstances be reduced in size. If more than one fitting is used in the line the entire installation beyond the first fitting should be increased in size. Such

piping should be well supported Improper support of the outlet pipe may result in leakage of the valve on account of vibration. A pop valve should not be installed in a horizontal position.

306. The methods of testing installed safety-valves are specified and described in A.S.M.E. Code. Pars. 275 and 391.

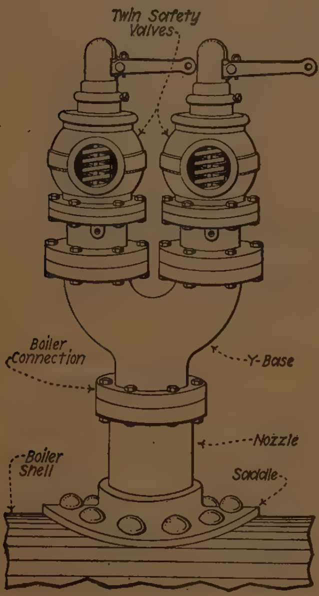


Fig. 245.—Twin safety valves, properly mounted.

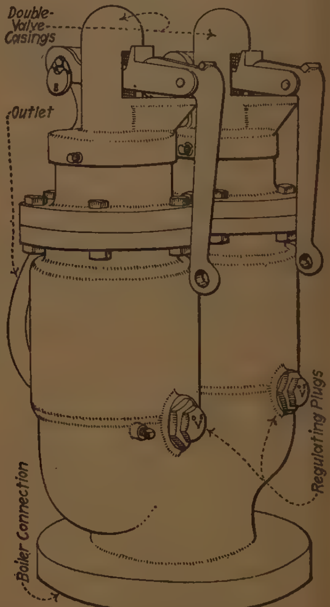


Fig. 246.—Ashton duplex pop safety valve.

307. An accumulation test for checking the relieving capacity of the safety-valve equipment of a boiler is made by forcing the fire under the boiler to the limit of furnace capacity while all outlets, except the safety-valve or valves, are closed against escape of steam from the boiler. In this test the safety-valve equipment must show a relieving capacity (A.S.M.E. Code) sufficient to prevent the steam pressure from rising more than 6 per cent. above the opening or popping pressure.

Note.—An Accumulation Test Should Not Be Made If The Rate Of Firing Cannot Conveniently Be Increased Very Gradually, nor

if the conditions are such that the intensity of the fire cannot be kept under complete control. In a test of this kind provision should be made for liberating the steam through an auxiliary outlet that can be used in case the safety-valve fails to work properly. For a boiler under which coal is burned with natural draft, the auxiliary outlet should have an area of not less than one square inch for each two square feet of grate surface.

308. In Operating A Boiler, Raising The Steam Pressure To The Blowing-Off Point, Except As A Test Precaution, Should Be Avoided.—Considerations of economy dictate this, inasmuch as the steam discharged through a safety-valve represents a measureable loss of heat energy and money. The following example is illustrative.

Example.—A 3-in., 45-degree, beveled pop safety-valve blows during an average period of 4 min. in each hour of a 24-hr. run. The average lift of the valve is 0.09 in. The blow-back is from 100 to 97 lb. per sq. in. gage. What is the resulting expense if the coal costs $4.00 per ton, and 8 lb. of water are evaporated for each pound of coal burned? Solution.—Formula from Par. 420, A.S.M.E. Code: $W = 110\ PDL$, wherein, W = weight of steam discharged per hr., in lb. P = average absolute pressure of steam, in lb. per sq. in. D = inside diameter of valve seat, in in. L = vertical lift of valve disc, in in. The average absolute pressure = $(100 + 97) \div 2 + 14.7 = 113.2$ *lb. per sq. in.* Substituting in formula: $W = 110 \times P \times D \times L = 110 \times 113.2 \times 3 \times 0.09 = 3362$ *lb. of steam per hr.* Minutes of total discharge per day $= 4 \times 24 = 96$ *min.* or 1.6 *hr.* Steam discharged in 24-hr. run $= 3362 \times 1.6 = 5379$ *lb.* Coal required to evaporate $= 5379 \div 8 = 672$ *lb.* Cost $= 672 \div 2000 \times 4.00 = \$1.34$ *per day;* or in a month of 30 days: $30 \times 1.34 = \$40.20$.

309. Safety-valve requirements and specifications are divided by the A.S.M.E. Code into three divisions as determined by the character of the installation: (1) *Power boilers, new installations.* (2) *Power boilers, existing installations.* (3) *Heating boilers, new installations.*

310. Some of the important safety-valve specifications for new installations are given in brief below. These are from the A.S.M.E. Code, Par. 269 *ff*.

1. When the relieving capacity must be over 2,000 lb. per hr. use 2 safety-valves.

2. The relieving capacity must be great enough that the pressure in the boiler will never rise over 6 per cent. above the maximum allowed

boiler pressure, or 6 per cent. above the highest pressure-setting of any valve.

3. One or more valves should be set at or below the maximum allowable working pressure.

4. Weighted-lever safety-valves shall *not* be used.

5. Relieving capacities are to be based on: (1) 6 lb. of steam per hr. per sq. ft. of boiler heating surface for water-tube boilers. (2) 5 lb. for all other boilers with maximum allowable working pressures over 100 lb. per sq. in. (3) 3 lb. for 100 lb. per sq. in. or less. Superheating surface is not included.

FIG. 247.—A Muffled safety valve (American Steam Gage & Valve Mfg. Co.)

6. No other valve of any description shall be used with a safety-valve. A safety-valve should be located as close as possible to the boiler.

7. When a muffler (Fig. 247) is used, it shall not cause any back pressure or interference with discharge.

8. Blow-down for boilers shall not be over 4 lb. when the steam pressure is less than 100 lb. per sq. in.; not over 6 lb. for 100 to 200 lb. per sq. in.; not over 8 lb. for boiler pressures over 200 lb. per. sq. in.

10. A lifting device is required for raising the seat 1/16 in. when no pressure is on the boiler.

11. Safety-valve springs shall not be used for pressures over 10 per cent. above or below that for which they are designed.

12. Every superheater shall have one or more safety valves near the outlet.

13. Valves discharging superheated steam shall have steel bodies, valve seats of nickel composition or equivalent, and the spring outside the valve.

311. The safety-valve specifications for existing power boiler installations (A.S.M.E. CODE, Par. 389 *ff*) are no different than those for new installations, excepting that lever safety valves are permitted. When a lever safety-valve is used its capacity shall be taken as 2/3 that given for pop safety-valves of the same size (see capacity table in A.S.M.E. CODE).

312. Safety-valves for steam heating boilers (A.S.M.E. CODE, Par. 347*ff*) shall be pop safety-valves of the spring-loaded type which cannot be set for a pressure greater than 15 lb. per sq. in. No valve should be less than 1 in. or greater than 4½ in. standard pipe size. The sizes are determined from the grate area as indicated in a table in the CODE. Other

requirements are similar to those above specified in connection with safety-valve installations for power boilers.

313. Feed-water Inlets Are Necessary For All Steam Boilers. Since the water in the boiler is converted to steam and passes out as such, feed-water must be supplied for replenishment. The feed-water may be forced into a boiler by a pump, by an injector, or other device. Feed-piping must carry the water from the feeding apparatus to the boiler. Inlets, valves and other required appurtenances must be so arranged as to provide maximum effectiveness.

314. The Location Of The Feed-water Inlet Of A Boiler Is Important.—The following are determining factors: (1) *The tendency of the comparatively cool feed-water to set up stresses due to unequal expansion in the boiler plate and tubes.* (2) *Liability of the boiler plate to deterioration on an area near the discharge orifice.*

315. The feed pipe of a horizontal return tubular boiler for power purposes should (A.S.M.E. Code) enter the front

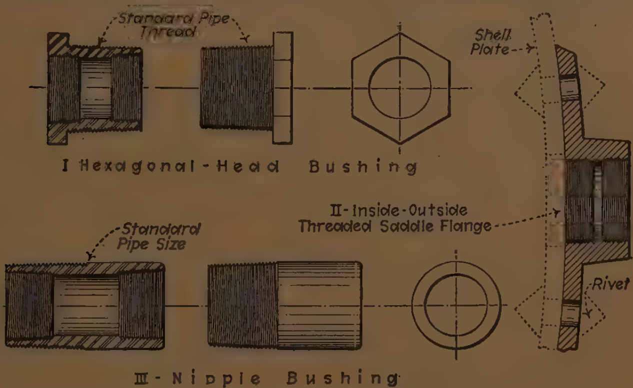


Fig. 248.—Boiler bushings and flange (A.S.M.E. Code).

head immediately above the tubes and should extend back about ⅗ of the length of the boiler. The water should be discharged above the central rows of tubes. By flowing through a length of pipe inside the boiler, the feed-water becomes heated to a comparatively high temperature. The piping should be securely fastened above the tubes. The attachment of the feed-pipe to the head of the boiler should be made with a bushing (Fig. 248) or flange.

NOTE.—In boilers of all types which employ an internal extension of the feed pipe, a boiler bushing (Fig. 248), or its equivalent, must be used for attaching the feed pipe to the head or shell. (A.S.M.E. CODE, Par. 315).

316. Boiler Feed-Water Should Not Be Discharged Near A Riveted Joint Or Furnace Sheet (A.S.M.E. CODE).—Feed-water is always cooler than boiler water. The comparatively-cool feed-water would chill and contract the plate or seam upon which it might be permitted to discharge. The local contraction thus produced would cause severe straining there of the metal. A permanent weakening tendency would also develop in the material of the plate or seam.

317. Feed-water may be discharged in the form of a spray by allowing it to spill over the edge of a pan (Figs. 249 and 250).

FIG. 249.—Top feed and spray pan in horizontal return-tubular boiler.

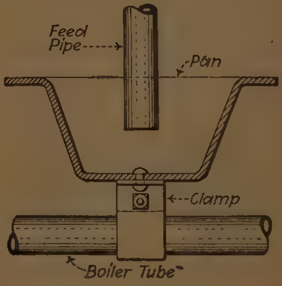


FIG. 250.—Detail of spray pan

The *spray-pan* may be a long trough with saw-tooth edges. This method is objectionable on account of a tendency of the sprayed feed-water to entrain with the outgoing steam current. Such entrainment may be obviated by locating the spraying device as far as possible from the steam connection.

318. Feed-Water Should Be Discharged In That Region Of The Water Space Where Ebullition Is Least Violent.—Precipitation of the impurities in the mud-drum or adjacent to the blowoff orifice is thus facilitated.

319. The Feed Piping Should Be So Jointed And Located That It May Be Easily Cleaned.—The water deposits sediment and scale-forming material in the pipe. The discharge

capacity of the pipe is thus diminished. The feed pipe should be cleaned each time the boiler is cleaned.

NOTE.—Feed-pipe installations may be observed in the following illustrations: Figs. 47, 54, 57, 60, 67 and 77.

320. A Feed Pipe Shall Be Provided With A Check Valve Near The Boiler And A Valve Or Cock Between The Check Valve And The Boiler.—When two or more boilers (A and *B* Fig. 251) are fed from a common source, there shall also be a globe valve, *G*, on the branch to each boiler, between the check valve, *C*, and the source of supply, *S*. Whenever globe valves are used on feed piping, the inlet shall be under the disc of the valve. (A.S.M.E. CODE, Par. 317.)

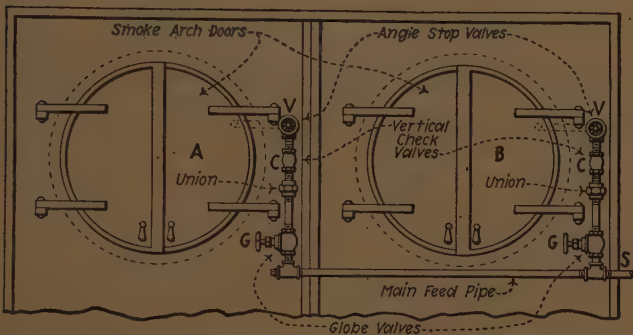


FIG. 251.—Feed pipe connections to two horizontal return tubular boilers.

321. A Check Valve Is Designed To Permit Flow In One Direction Only (Fig. 252).—These valves restrain automatically the back flow of water, from the boiler through the feed pipe, when the pump or injector is stopped. Valves of certain types may be installed either horizontally or vertically in the line, while others may be used only in a horizontal line.

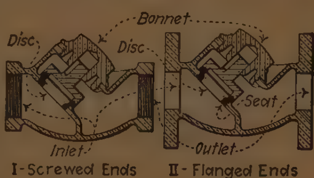


FIG. 252.—Check valves.

322. The stop valve or cock, between the check valve and the boiler (*V*, Fig. 251) is used to isolate the check valve from the boiler for inspection or repair. The stop valves, *G*, be-

tween the check valve and the source of supply is for regulating the supply or cutting it off altogether.

323. The size of pipe required for boiler-feed lines is determined in accordance with the velocity of flow through the pipe. The curve shown in Fig. 253 gives the maximum and minimum pipe sizes used by feed pump and manufacturers for pump connections for boiler-feed lines.

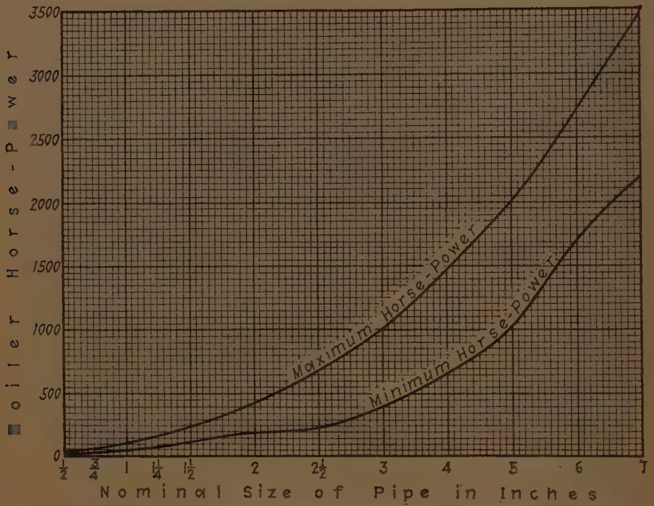


FIG. 253.—Graph showing feed pipe sizes for boilers of different horsepowers.

324. Two Stop Valves Should Be Placed In The Steam Connection Leading From Each Boiler In A Battery, To The Steam Main.—This is required by the A.S.M.E. CODE when two or more boilers are connected to a steam main. One of these valves should, preferably, be an automatic stop valve.

325. Automatic non-return stop valves in the main steam connections of boilers are necessary (Figs. 254, 255 and 256) for the following principal reasons: (1) *They provide a means for automatically cutting a boiler from the main line in the event of tube-failure, blowing out of a manhole gasket, rupture of a blowoff connection, or similar accident.* (2) *They render certain that no steam from the main line will*

be admitted to a cold boiler when there are workmen inside of it. (3) *They provide a means whereby a boiler may be automatically cut into service when its pressure is equal to the line pressure.*

326. Automatic stop valves for use in the main steam connection of boilers may be divided into two classes: (1) *Single-acting non-return stop valves which close automatically when steam begins to flow from the main header*

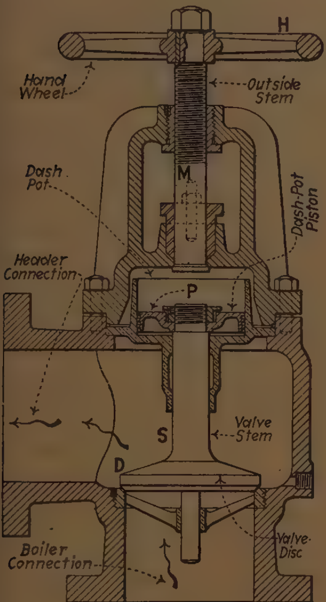


FIG. 254.—Foster automatic non-return stop valve.

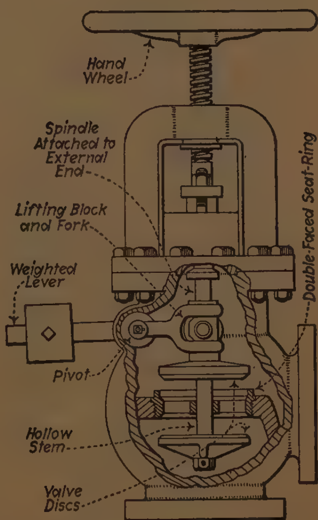


FIG. 255.—The Lagonda double-acting automatic cut-off boiler valve.

into the boiler. (2) *Double-acting stop valves which close automatically either when an abnormal flow of steam from a boiler begins, or when steam begins to flow from the main header into the boiler.*

327. The function of a single-acting automatic stop valve (Fig. 254) is to stop a flow of steam from the main header into the boiler in case any part of the boiler is ruptured. Also, it automatically cuts the boiler in and out of service. When the pressure in the boiler, becomes as great as that in the main header, the valve opens automatically.

EXPLANATION.—The main working part of the valve (Fig. 254) is a disc, *D*, which is seated as in an ordinary stop valve. The disc is connected by a stem, *S*, which has a dash-pot piston, *P*, on its upper end. The dash-pot is designed to cushion the opening and closing of the valve. If the disc were not thus restrained, it would chatter and hammer itself to destruction. When the steam pressure under the disc becomes a little greater than that above it, the valve opens. It has a tendency to remain open as long as steam flows upward. When the pressure below the valve diminishes, and the steam begins to flow downward, the valve closes immediately. The valve may be closed definitely by screwing down the stem, *M*, with the hand-wheel, *H*. Thus it is evident that an automatic non-return stop valve is essentially a dash-pot-cushioned check valve provided with a screw for keeping it closed when required. It performs a function in the branch steam line somewhat similar to that of the check valve in the water feed line.

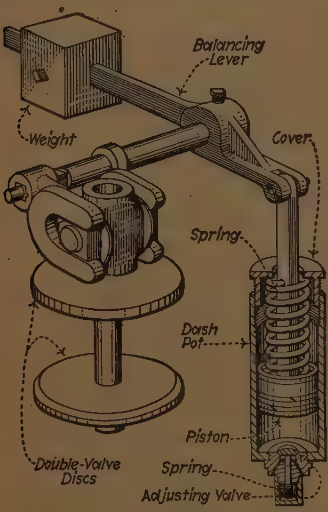


FIG. 256.—Cushioning and balancing mechanism of Lagonda automatic, double-acting, stop valve.

328. The function of a double-acting automatic stop valve (Fig. 255) is three-fold. (1) *It isolates the boiler from the main header, by closing against the header pressure in the event of rupture of any part of the boiler.* (2) *It isolates the boiler from the main header, by closing against the boiler pressure, in the event of rupture of the main header or of apparatus which is supplied with steam from the main header.* (3) *It automatically cuts the boiler in and out of service under normal operating conditions.*

EXPLANATION.—The valve in Fig. 255 has two discs. One disc is above and the other is below a double-faced seat. The hollow stem which connects the two discs, is free to slide upon a spindle by which the valve may be closed by hand by turning the handwheel. With a normal flow of steam, the discs are held balanced in the open position (Fig. 255) by a weighted lever and dash pot (Fig. 256) attached externally. This balancing device serves to control and cushion the movements of the discs. Necessary adjustment may be made by screwing the cover of the dash pot up or down, thus changing the tension of the spring. When the valve is properly adjusted, either a downward flow of steam, or an

excessively rapid upward flow, will close it. When the upper disc is seated it is not possible to open the valve by hand. But when the lower disc is seated the valve may be opened.

329. Automatic Stop Valves May Increase The Economy Of A Plant.—It is uneconomical to run underloaded boilers. They should be cut in and out of service in conformity with the load requirements. With ordinary stop valves alone on the connections, this duty is, in most cases, neglected on account of the effort and inconvenience involved in opening and closing the valves. But with automatic valves in working order, the task is reduced to a simple matter of banking the fires under the unnecessary boilers when the load drops off and leveling them again when the load increases. The automatic valves will respond to the changed conditions. Without such valves deadened boilers may be permitted to float along on a line and so become a source of loss, due to condensing of the steam which passes in from the main header.

330. An Ordinary Stop Valve Should Supplement The Automatic Stop Valve On The Main Steam Connection Of A Boiler.—It should be inserted in the line between the main header and the automatic valve. The automatic valve should be as close to the boiler as possible. The most important reason for putting in the supplementary valve—which may be either a gate or globe valve—is to provide a means for shutting off the line pressure from the automatic valve when the boiler is laid up for cleaning or repairs. At this time the automatic valve should be inspected so that no conjecture may exist as to its working condition. It should be thoroughly cleaned and all rubbing surfaces lubricated sparingly with graphite. All bearing surfaces should be free from abrasions or scratches which might prevent free action. Where the working pressure exceeds 125 lb. per sq. in., the valve must be "extra heavy."

NOTE.—Steam and drain-pipe connections for the bodies of automatic non-return stop valves are described in a following Sec.

331. A steam-gage (Figs. 31, 34, 37, 40, 41, 51, 54 and 78,) is an instrument for indicating the steam pressure in a boiler or other containing vessel. Ordinarily, a steam-gage registers

the pressure of the steam, above atmospheric pressure, in pounds per square inch.

332. Modern Steam-gages Are Generally Of The Bourdon, Or Spring-tube Type.—These gages operate through the

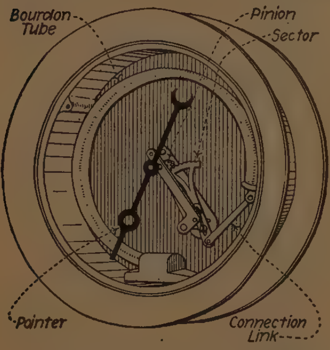


Fig. 257.—Interior view of steam gage with single Bourdon tube. (Ashton Valve Co.)

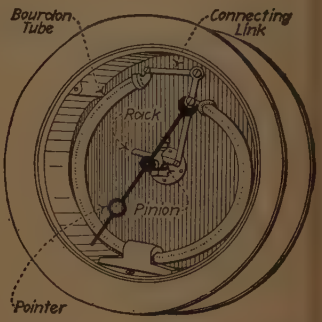


Fig. 258.—Interior of steam gage with double Bourdon tube. (Ashton Valve Co.)

tendency of a curved tube, (Figs. 257 and 258), which is of oval cross-section, to straighten out when pressure is applied internally. The spring tubes are made of brass or composition metal.

Note.—For a discussion of the principles of steam-gage operation see the Author's Practical Heat.

333. Every Boiler Should Have A Steam-gage.—The gage may be con-

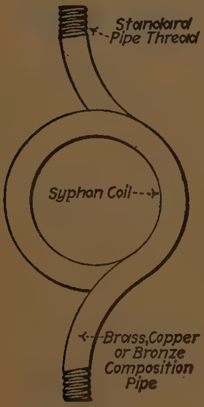


Fig. 259.—Simple form of siphon for steam gage connection.

Fig. 260.—Siphons with and without attached stop-cock for vertical and horizontal connection to steam gage (Crosby Steam Gage & Valve Co.)

nected to the steam space (Figs. 41 and 51), the water-column (Figs. 34 and 54), or to the connection to the

water-column (Fig. 78). Each gage must be connected to a siphon (Figs. 259, 260, and 261) or equivalent device with sufficient water capacity to prevent the steam from entering the gage tube. This is to obviate the deteriorating and disturbing effect of the high temperature of the steam on the material and mechanism of the gage (A.S.M.E CODE, Par. 296.)

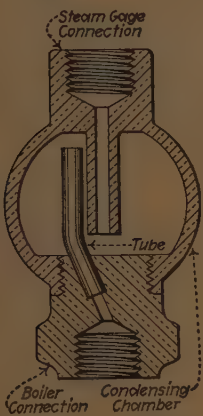


FIG. 261.—Sectional elevation of ball siphon and steam-gage connection.

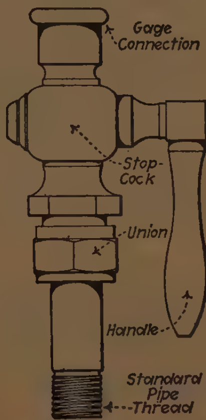


FIG. 262.—Stop cock for steam gage connection.

334. It Should Not Be Possible To Shut Off The Gage From The Boiler, Except By A Cock Placed Near The Gage.—Exception to this rule may be made when there is a long connection between the gage and the boiler. In such a case, a valve or cock may be placed near the boiler, but it must be of a type that can be locked or sealed open. The handle of the cock (Figs. 260 and 262) should be parallel to the pipe in which it is located when the cock is open. Connections to gages should be of brass, copper or bronze composition (A.S.M.E. CODE, Par. 296).

335. The Dial Of A Steam-gage Should Be Graduated To Not Less Than 1½ Times The Maximum Allowable Steam Pressure On The Boiler (A.S.M.E. CODE, Par. 297).—This insures that the true pressure will be indicated in the event that the safety-valve sticks, or, for any reason, the steam pressure exceeds that allowable.

336. Each Boiler Should Be Provided With A ¼-in.-pipe-size Valved Connection For Attaching A Test Gage (A.S.M.E. Code, Par. 298).—This special test-gage connection is for use when checking, with a standard test gage, the accuracy of the boiler steam-gage.

337. A water column (Figs. 54, 56, 57, 59, and 60) is a vessel extraneous to the boiler and suitably connected with it to which water gages and low- and high-water alarms may

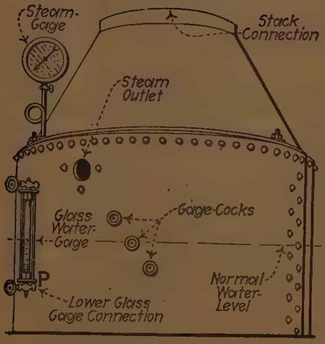


Fig. 263.—Glass water-gage and try-cocks attached to small vertical fire-tube boiler.

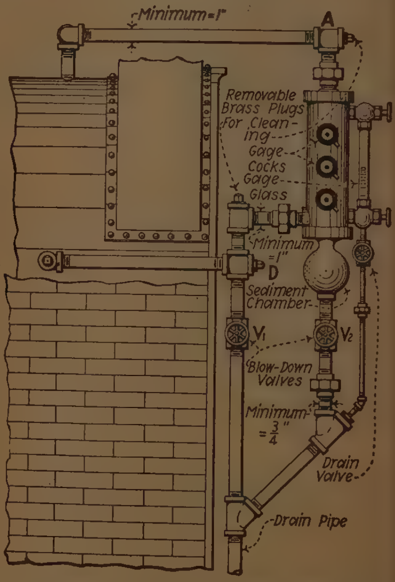


Fig. 264.—A properly-connected water column. (At *A* and *D* either outside-screw-and-yoke-type gate valves or stop cocks, with levers permanently fastened thereto, may be used.)

be attached. The steam-gage may also be attached to the water column. Water columns are indispensable for horizontal return tubular boilers as commonly set. Some types of boilers (Figs. 41, 42, 44, 51 and 263) require no water columns.

338. The pipe connections for a water column should be at least 1-in. pipe size. The water connection should be of brass. It should be filled with a cross *D*, (Fig. 264) to permit

cleaning. The steam connection to the water column of a horizontal return tubular boiler should be taken from the top of the shell or the upper part of the head. The water connection should be taken from a point not less than 6 in. below the centerline of the shell (A.S.M.E. CODE, Par. 320–322).

339. The height of the water-column relative to the lowest water level that can be maintained with safety is important. When attached to a horizontal return tubular boiler, the water-column should be installed at a height that will bring the center of the hole, which is tapped for the lower valve of the glass gage, at least 2 in. above the top row of tubes (Fig. 265). This insures about 3 in. of water above the tubes when the water is just disappearing from the glass gage. A water column should be of such size and so located that the normal water level is near the center of the column (Fig. 56).

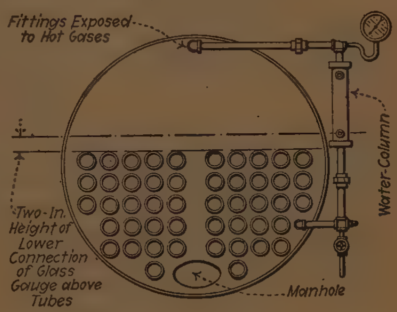


FIG. 265.—Water column set at proper height.

340. When the water gages are attached directly to the boiler (Fig. 263), the lower glass-gage connection should be, in the case of a horizontal fire-box boiler (Fig. 51) at a point about 1 in. above the crown sheet. For a portable vertical fire-box boiler (Fig. 263), it should be at a point, *P*, about three-fourths the height of the shell.

341. Piping Between Water-column And The Boiler Should Have No Outlet Connections Except For Damper Regulator, Feed-water Regulator, Drains Or Steam-gages (A.S.M.E. CODE, Par. 295).—Disregard of this rule (Fig. 266) may lead to trouble. It is important that the full boiler pressure be conveyed to the surface of the water in the column. A flow of steam to some other apparatus ("as to Steam-Jets," Fig. 266) than the water column, might result in a decreased pressure above the water in the column. This would cause the water

to stand higher in the glass gage than in the boiler. The false indication due thereto might result in an accident. Fig. 264, illustrates a correctly-connected water column.

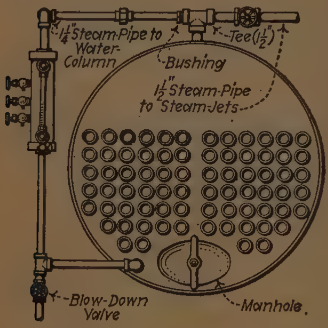


FIG. 266.—An incorrect and dangerous arrangement of water column and steam-jet connected to same outlet from boiler.

342. Shut-off Valves May Be Used In The Connections Between The Water-column And The Boiler.—When such valves, are used "they shall be either outside-screw-and-yoke-type gate valves, or stop cocks which have levers permanently fastened thereto, and such valves or cocks shall be locked or sealed *open*." (A.S.M.E. CODE, Par. 293.) The locations should be between *A* and *D*, Fig. 264, and the boiler. A conservative arrangement of a water column piping is shown in Fig. 267 wherein the shut-off valves are shown in the horizontal pipes.

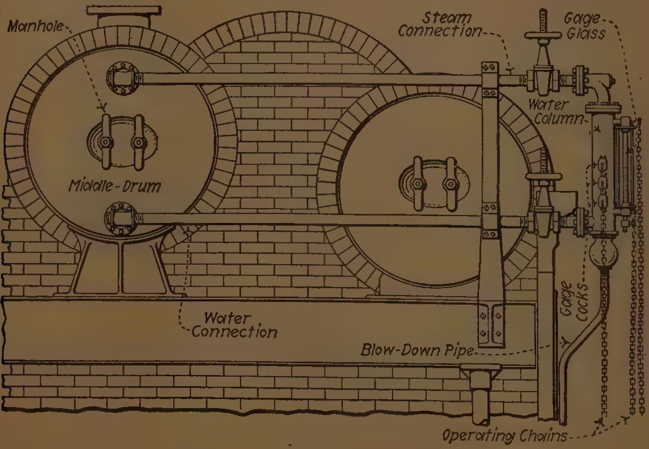


FIG. 267.—Water column and connections on Stirling water-tube boilers.

343. The glass water gage (Fig. 268) is usually in the form of a tube which is inserted between valves, *S* and *W*. These valves control the steam and water passages to the boiler.

The level of the water, as seen in the glass tube, coincides with the water-level in the boiler. By opening the drain cock, *D*, a current of steam is allowed to sweep through the tube and blow out any sedimental deposits. Fig. 268*A* shows a gage glass which conforms to the *A.S.M.E. Code* requirements as given in Par. 427 of the appendix to the *Code.*

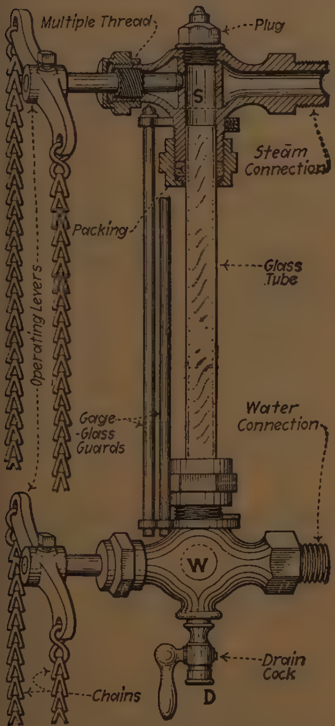


FIG. 268.—Water gage with quick-closing valves.

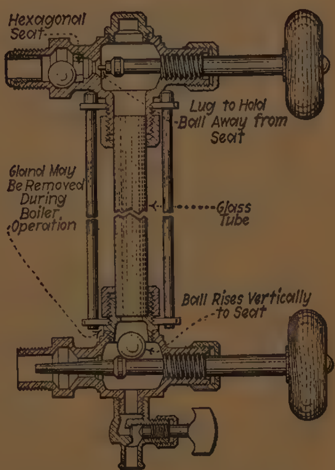


FIG. 268A.—A gage glass which fulfills requirements of A.S.M.E. Code. (Pemberthy Injector Co.)

344. Gage cocks or try cocks (Fig. 263 and 264) are supplementary water gages. Each boiler should have at least three of these cocks. The middle one, when there are three, should be at the normal water level. The higher one and the lower one are placed at the highest and lowest permissible water levels. The lowest cock, when opened, should allow only

water to escape, and the highest one, only steam. The intermediate cock may emit a mixture of water and steam if the water is at the correct level. An ordinary wooden-hand-wheel gage cock is shown in Fig. 269. When the gage cocks are so high from the floor as to be difficult to reach, they are operated by chains and are automatic in closing. Figs. 270, 271, 272, 273 and 274 show some types of gage cocks.

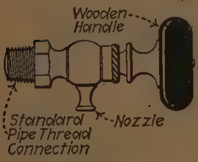


FIG. 269.—Gage cock of the simplest form.

345. The Water-gage Glass May Be Enclosed (Fig. 275).—This provides protection to the operators when a gage glass breaks. The protector, or case, is made of very tough plate glass.

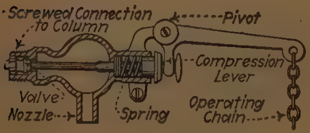


FIG. 270.—Sectional view of Reliance self-closing, spring-operating gage cock.

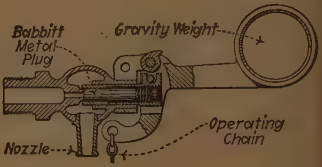


FIG. 271.—Standard gage cock (Ohio Brass Company).

346. To Prevent A Continuous Flow Of Water And Steam When A Gage Glass Breaks, An Automatic Valve May Be Used (Fig. 276).—When the gage glass breaks and water and steam begin to pass through the valves the balls take positions over

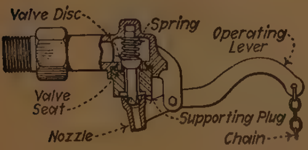


FIG. 272.—Robertson vertical-valve gage cock.

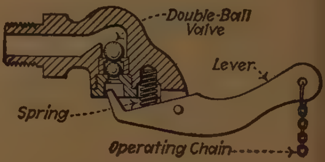


FIG. 273.—Nason double-ball valve gage cock.

the openings, thus stopping the flow. The balls should be non-ferrous. The ball seat in the upper valve should be square or hexagonal, thus insuring against a tightly seated valve. This is a guarantee that the valve will never become acci-

dently closed, under working conditions. The ball in the lower valve should rise vertically to close the water opening. Other details may be found in A.S.M.E. CODE, Par. 427.

347. Low- and High-water Alarms May Be Included In The Water-column.—These alarms consist of an automatically-operated whistle which gives a signal when the water becomes too low or too high. Fig. 277 shows such an attachment in a water-column. Details of operation may be observed in Fig. 278. High water in the column lifts the upper float, *U*, thus

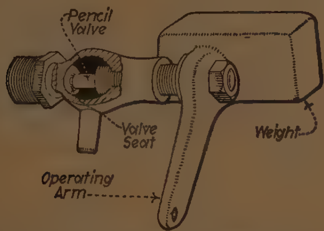


FIG. 274.—Huyette weighted-lever gage cock.

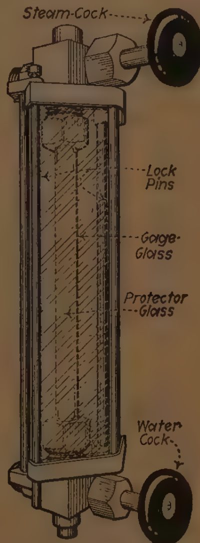


FIG. 275.—"Durable" gage glass shield in service position.

opening the steam passage to the whistle When the water becomes low, the weight of the lower float, *L*, opens the whistle valve. Figs. 279 and 280 show types in which a single, loose float operates the whistle valve. Other types may give only the low-water signal.

348. Boiler blow-off apparatus consists of valves and pipes so connected that part or all of the contents of a boiler may be allowed to escape through them at the will of the operator. This apparatus is divided into: (1) *Surface blow-off equipment.* (2) *Bottom blow-off equipment.*

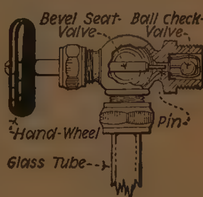


FIG. 276.—The Crosby automatic water-gage valve.

349. The surface blow-off apparatus (Figs. 281 and 282) is for the purpose of blowing off scum from the surface of the water. The scum is formed by impurities in the water which rise to the top. It is detrimental in that it does not allow the

steam bubbles to escape freely. Thus it causes a violent agitation of the water. Part of the scum may rise with the steam into the mains and thus be transmitted to the engine or other equipment. Scoring of valves, cylinders and pistons, an impairment of lubrication and a racing of the engine may result. The racing is due to the inability of the relatively-weak governor mechanism to overcome the excessive valve

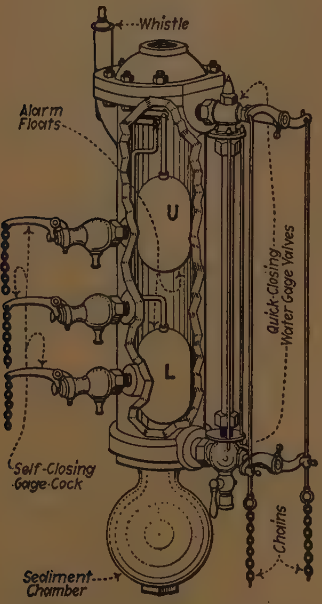


FIG. 277.—Reliance water column showing inside and outside fittings.

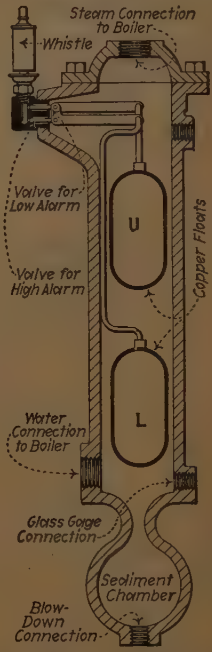


FIG. 278.—Working mechanism of Reliance high- and low-water alarm.

friction induced by the scum and deposits which are carried into the engine.

EXPLANATION.—The skimmer, *S*, in Fig. 281, is funnel-shaped and square in cross-section. It should be located about ⅓ the length of the boiler from the back head and at a height such that the outlet from the funnel will be submerged at the lowest stage of the water level. The upper edge of the funnel should project above the surface of the water at its highest level. These conditions are necessary for proper collection of the scum and impurities.

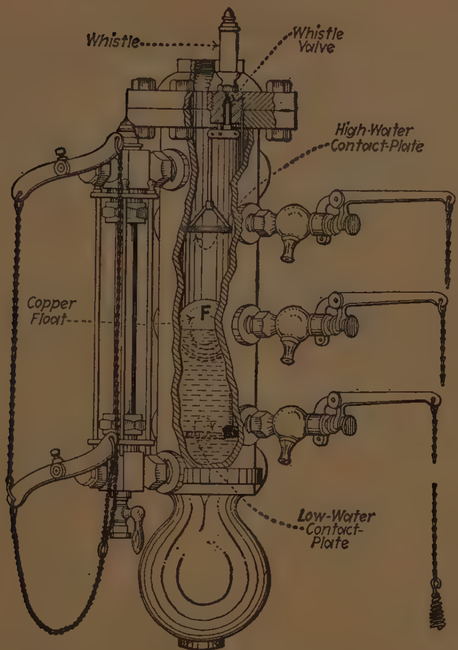


FIG. 279.—Combined high- and low-water alarm. (Wright-Austin Co.)

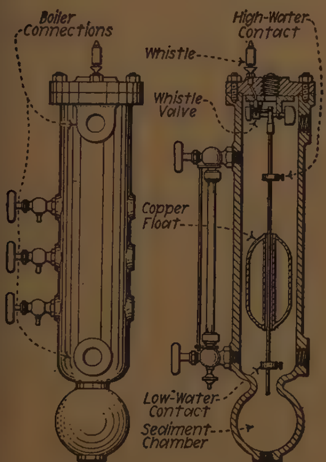


FIG. 280.—High-and low-water alarm. (Illinois Engineering Co.)

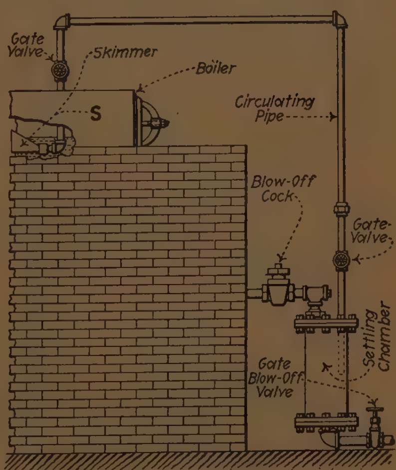


FIG. 281.—Surface blow-off apparatus.

350. Surface blow-off piping should not exceed 1¼ in. pipe size. When inside and outside pipes are used, they should form a continuous passage. This may be accomplished by using bushings or a flange similar to those of Fig. 248. The material for the bushings may be brass or steel (A.S.M.E. CODE, Par. 307).

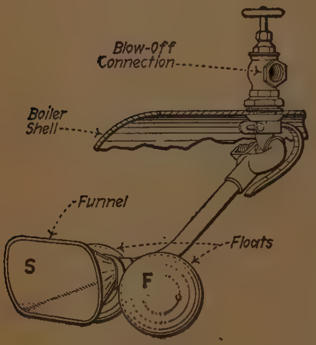


FIG. 282.—Skimmer which floats. (Buckeye Boiler Skimmer Co.)

351. The bottom blow-off apparatus is for the purpose of blowing-off the sludgy sediment which collects at the bottom of the boiler or in the mud-drum. This outlet is also used to lower the water-level in the boiler. This may be necessary when excessive priming occurs, and for emptying the boiler for cleaning or other purposes. See also a following Sec. for BLOW-OFF PIPING AND ITS MANAGEMENT.

352. The bottom blow-off pipe connection should be made to the lowest water space practicable The size of the pipe should never be less than 1 in. nor greater than 2½ in. A smaller pipe might become clogged by scale. A larger pipe would cause a too-rapid loss of water. Fig. 36 shows a long radius bend designed to prevent lodging of scale and dirt in the pipe. The piping, when exposed to the products of combustion should be protected by fire-brick, a cast-iron sleeve or a covering of non-conducting material.

353. Since the water does not circulate through the blow-off pipe, it does not carry away the heat. The result is apt to be an overheating which may cause its destruction. When coverings are provided, they should be such as may be taken off without disturbing the piping. For example, the covering of cast-iron should be split so it may be readily removed and replaced. Fig. 283 illustrates a brick protecting pier in front of vertical pipe and a cast-iron sleeve over the horizontal length. The passage for the pipe through the wall should permit free expansion. The blow-off pipe should be extra

heavy from the boiler to the valves. No reducers or bushings should be used.

NOTE.—Fig. 284 shows the piping connections used when the feed water is fed through the blow-off pipe. This arrangement is to give a water circulation through the blow-off pipe, thereby preventing overheating.

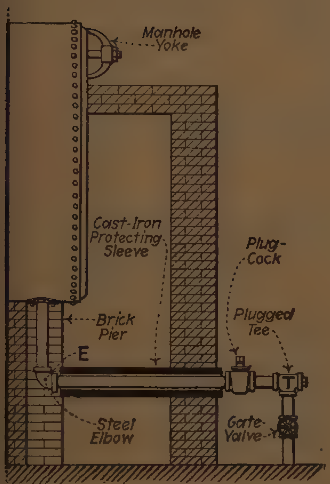


FIG. 283.—Blow-off apparatus of a return-tubular boiler.

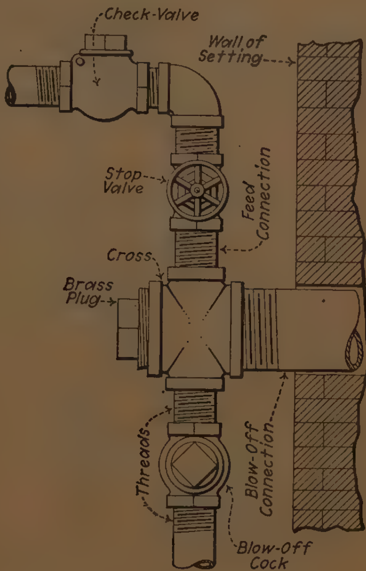


FIG. 284.—Feed pipe connected to blow-off.

354. The fittings in the blow-off pipe between the boiler and valves (*E* and *T* in Fig. 283) should be made of steel. Cast-iron fittings are not suitable for a blow-off connection. They are liable to crack when subjected to the sudden high temperature changes incident to the use of the apparatus.

355. The requisite number and disposition of the blow-off valves of a boiler installation (A.S.M.E. CODE, Par. 311) are as follows: Two valves, or a valve and a cock, on each stationary boiler carrying a steam pressure over 125 lb. per sq. in. gage. One extra-heavy valve on each portable boiler carrying a steam pressure over 125 lb. per sq. in., gage. If

there are multiple blow-off pipes on a single boiler, a master valve may be used in the common blow-off pipe to which the multiple pipes connect. Only one valve in each multiple pipe is then necessary.

356. Special Designed Valves Should Be Used In The Blow-off Piping.—Ordinary globe or gate valves are not suitable. They impede the passage of solid matter in the current of water which issues from the boiler. Fig. 285 shows a blow-off cock. Typical forms of blow-off valves are shown in Figs. 286, 287 and 288.

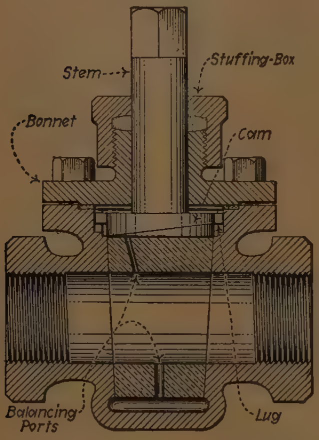


Fig. 285.—Homestead blow-off cock.

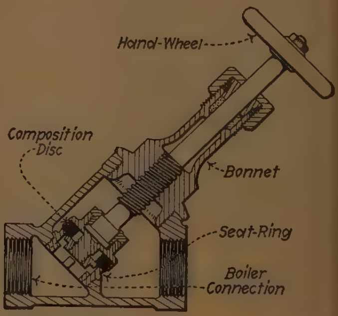


Fig. 286.—Y-type blow-off valve.

357. A blow-off tank (Figs. 289 and 290) is a cylindrical vessel made of boiler plate and set in some convenient location below the level of the boiler blow-off orifice. The boiler blow off pipe is connected directly to it. Its function is to trap the hot discharge from the boilers. The entrapped water cools in the interval following a blow-down of the boilers. The water thus cooled is displaced by the hot water discharged from the boiler in the next suceeding blow-down. By this means the damage to sewer, which would result from discharging the hot water directly into it, is avoided. The syphon breaker (Fig. 290) prevents a syphoning action through the outlet extension into the tank.

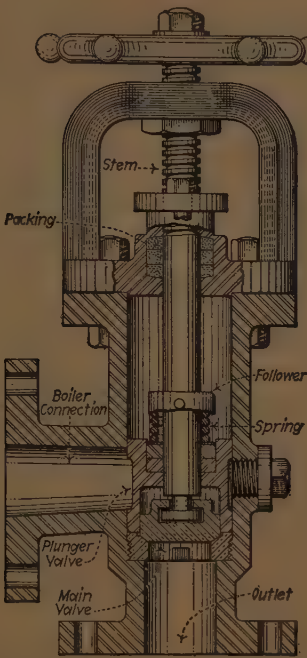


FIG. 287.—Vance double-disc blow-off valve.

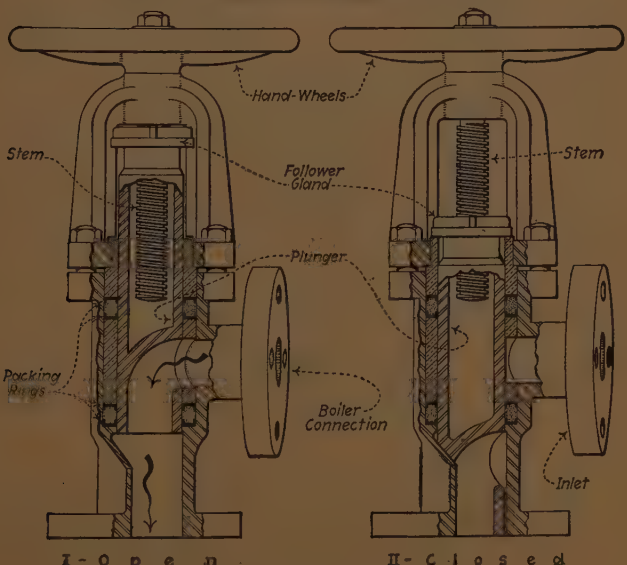


FIG. 288.—Simplex angle blow-off valve.

NOTE.—THE PIPING CONNECTIONS TO A BLOW OFF TANK should be so proportioned and arranged that the pressure within the tank can not become excessive. Blow-off tanks are not designed as pressure tanks and hence are liable to explosions if subjected to considerable internal pressure. To protect a blow-off tank from explosions, a vent pipe, of a size greater than that of the blow-off-pipe inlet, should be provided direct to the atmosphere. Also, the water connection to the sewer should be of a size larger than the steam inlet to the tank.

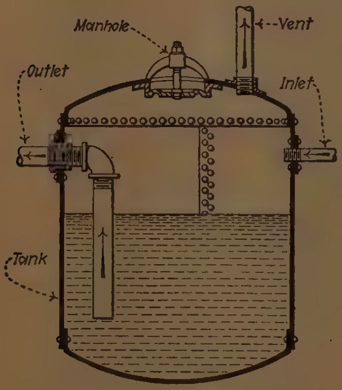


FIG. 289.—A blow-off tank.

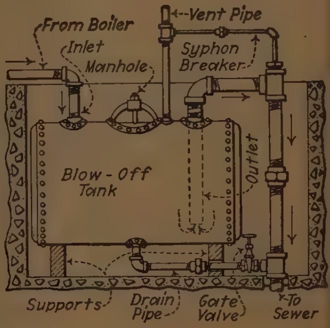


FIG. 290.—Typical blow-off tank with piping pertaining thereto.

358. Soot Should Not Be Allowed To Accumulate On The Boiler Heating Surfaces.—Soot is an excellent heat insulating material. Hence the quantity of heat transmitted to the water in the boiler will be diminished if a coating of soot is permitted to stay on or in the boiler tubes. Soot removals should be frequent—from one to several times per day, according to the fuel and the conditions of firing.

NOTE.—Usually the substance that settles and adheres to the tubes is a mixture of soot, ash, and dust. If this is allowed to remain it may fuse and cake. It thus makes a scale which is difficult to remove. Fresh accumulations of soot on the boiler surfaces may be easily blown off. The word "soot" will be used here to mean a mixture of soot, ash, and dust.

359. Soot may be removed from the boiler heating surfaces in the following ways: (1) *By brushing.* (2) *By scraping.* (3) *By blowing.* If the soot has become caked, the first and

second methods must be used. If the accumulation is loose and flocculent it may be blown off with air or steam blasts.

Explanation.—Scraping and brushing are especially adapted for removing soot-deposits from fire tubes and flues. A typical form of

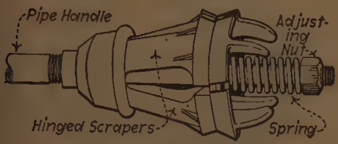


Fig. 291.—Tube scraper.

Fig. 292.—Combination brush and scraper.

tube-scraper is shown in Fig. 291. When the hardened soot has been cut loose from the tubes with a scraper, it may either be brushed out, or blown

Fig. 293.—The Robinson soot blower.

out with air or steam jets. A combination flue- or tube-brush and scraper is shown in Fig. 292. A portable soot-blower is shown in Fig. 293. The

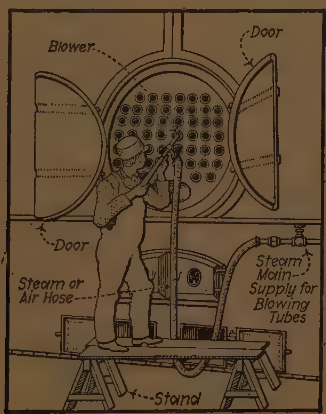


Fig. 294.—Blowing the tubes.

manner of using it is illustrated in Fig. 294. By pressing the head, H, against the end of a tube, the steam nozzle is opened. Thus a jet of steam is blown through the tube. An air- and steam-jet blower is shown

in Fig. 295. The steam jet issuing from the nozzle creates a partia vacuum. The suction thus produced causes an inrush of air. Th current of mingled steam and air issues around the cone.

360. Boilers Should Be Equipped With Permanently-At-tached Soot-blowers (Fig. 296, 297, 298 and 299).—Such apparatus mitigate the disagreeable features of soot-blowing. Thus they conduce to vigilance in this detail of operation.

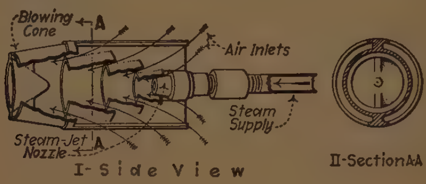


FIG. 295.—Tornado tube blower.

EXPLANATION.—The blower in Fig. 296 has a nozzle opposite to each boiler tube. Thus all of the tubes are blown simultaneously. The blower in Fig. 297 operates by horizontal rotation, about the axis of the boiler shell, of the manifold to which the nozzles are attached. The blower in Fig. 298 operates by rotation (about its own longitudinal axis) of the manifold to which the nozzles are attached. The blower in Fig. 299 has a single nozzle which can be swung from tube to tube. The

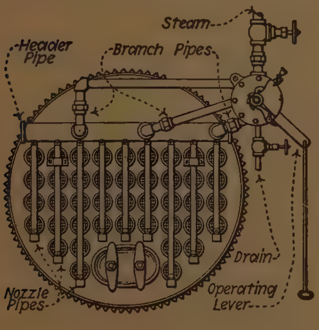


FIG. 296.—Stationary nozzle soot blower. (National Flue Cleaner Co.)

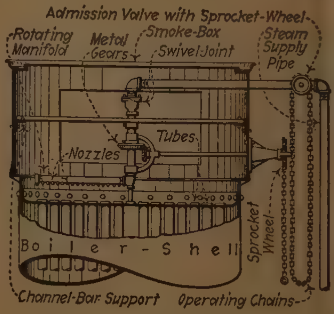


FIG. 297.—Manning vertical fire-tube boiler equipped with Vulcan soot blower.

indicator on the outside of the boiler front shows the different positions of the blow-pipe nozzle inside.

361. Dry Steam or Dry Air Should Be Used In The Operation Of Soot-blowers.—Wet steam or air causes some

of the soot to stick and cake. The caking of soot, from this cause, in water-tube boilers may progress to the extent of filling up the spaces between contiguous tubes. Such deposits can be loosened and removed only by jabbing them with iron rods or pokers.

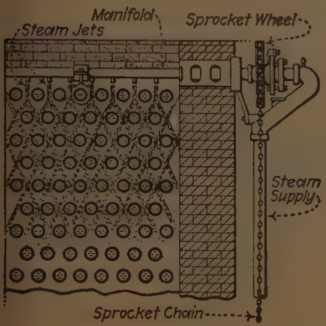


FIG. 298.—Permanently attached soot blower in a horizontal water tube boiler. (Diamond Power Specialty Co.)

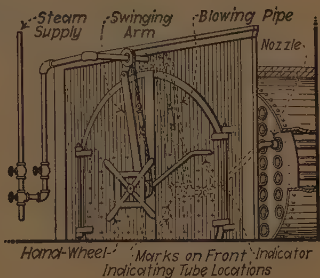


FIG. 299.—Single nozzle soot blower. (General Specialty Co.)

362. Proper soot-blowing improves the economy of boiler operation from 2 to 10 per cent. This has been demonstrated by tests. The rise in temperature of the flue gases after a day's run without blowing off of soot may be as much as 75 deg. Fahr. After several days' omission, the rise may be near to 175 deg. Fahr.

363. Mechanical devices for removing scale from the water surfaces of boiler tubes are of two general types, as follow: (1) *Those which jar the scale loose by the hammering action of a vibrating tool* (Figs. 300 and 301). (2) *Those which cut the scale loose by the cutting action of a revolving tool* (Figs. 302 and 303). Cleaners of the first type may be used in water-tubes (Fig. 300) or in fire-tubes (Fig. 301). Those of the second type are suitable only for water-tubes.

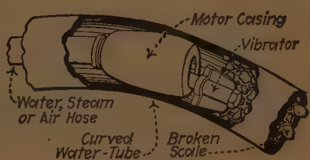


FIG. 300.—Vibrating hammer-head tube-cleaner for curved tubes. (William B. Pierce Co.)

Those of either type are adapted for use in both straight and curved tubes.

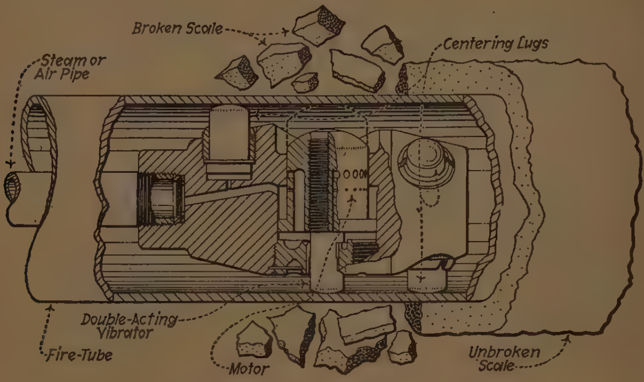


FIG. 301.—Vibrating tube-cleaner.

NOTE.—The cause of scale on the water surfaces of boilers, and the methods of scale-prevention and removal by the action of substances introduced into boilers with the feed-water, are discussed in Div. 24.

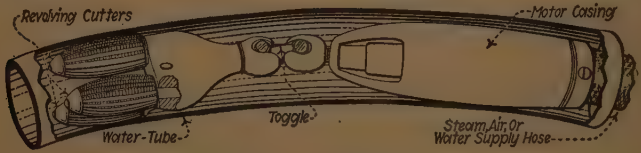


FIG. 302.—Revolving cutter tube-cleaner for curved tubes. (General Specialty Co.)

364. The energy for operating mechanical scale-removers may, for water-tube cleaners, be transmitted to the encased motors (Figs. 300, 301, 302, and 303) through the medium

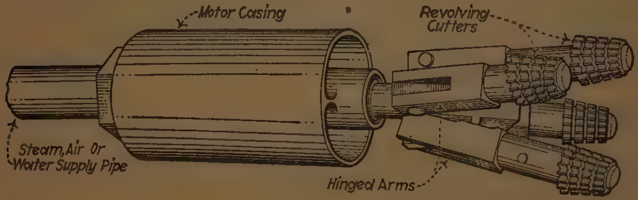


FIG. 303.—Revolving-cutter type of scale remover. (Liberty Mfg. Co.)

of steam-, air-, or water-pressure. For fire tube cleaners the medium may be either steam or air.

NOTE.—The operating motors of mechanical scale-removers are miniature engines which embody various applications of the turbine or rotary principle. See Author's STEAM ENGINES.

365. A fusible- or safety-plug (Figs. 304, 305, and 306) is a brass plug having a core made of some metal which melts

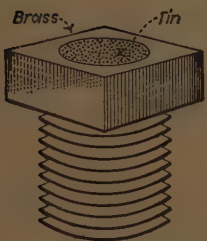


FIG. 304.—A fusible plug.

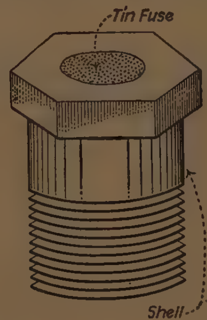


FIG. 305.—Fusible plug for inside insertion.

at a comparatively low temperature. It may also be in the form (Figs. 307 and 308) of a simple slug of readily-fused metal. Its function is to safeguard the boiler against damage from low water.

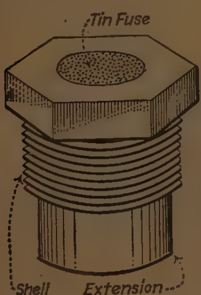


FIG. 306.—Fusible plugs for outside insertion.

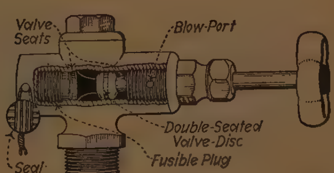


FIG. 307.—The Crosby sealed fusible plug.

366. Fusible Plugs May Be Attached Directly Or Indirectly To Boilers.—Direct attachment (Fig. 309) consists in tapping the plug directly into the metal of a shell, head or tube. Indirect attachment (Figs. 307 and 308) consists in locating the plug in a pipe or fitting which of itself, has direct connection

with the boiler, but which places the plug more or less remot[e]
therefrom.

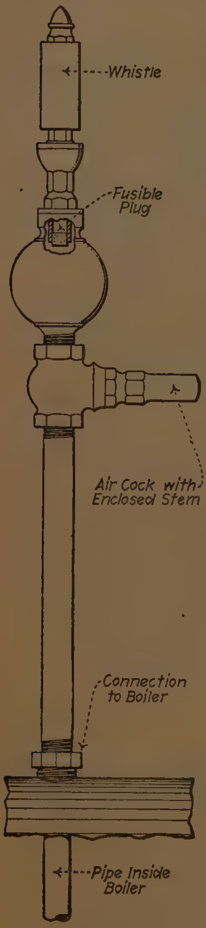


FIG. 308.—Fusible plug used in connection with whistle alarm.

367. Fusible plugs for direct attachmen[t] to boilers are of two general types, a[s] follows: (1) *Those which are inserted* (Fig[s]. 309) *from the fire side of the boiler metal*; (2) *Those which are inserted* (Fig. 309) *from the water side.* Either type of plug i[s] attached at some point coincident with th[e] lowest level to which the water may recede with safety. Normally, the inner end is covered with water. The outer end is ex-posed directly to the heat of combustion. When the water level falls low enough to uncover the plug, the heat which accumu-lates in the core causes it to fuse and blow out (Fig. 499). Warning of the danger is thus given. The fire may be quenched at the same time (Fig. 499).

368. Indirectly-attached fusible plugs (Figs. 307 and 308) are designed to melt at a lower temperature than are those

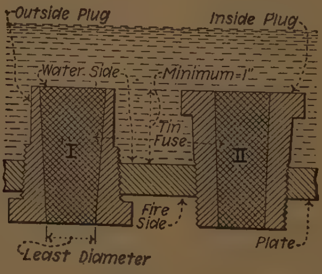


FIG. 309.—Fusible plugs inserted in boiler plate.

which are directly-attached. Normally, the plug is exposed to a temperature much lower than that of the steam. This is due to the body of comparatively stagnant water in the connection which intervenes between the plug and the boiler

interior. When this water drains out, by reason of the water level in the boiler having fallen too low, steam enters in its place. The excess of temperature thus produced causes the plug to melt and blow out. The escaping current of steam gives warning either by blowing a whistle (Fig. 308) or by issuing as a hissing jet. (Fig. 307).

NOTE.—Only directly-attached fusible plugs are considered in the specifications of the A.S.M.E. CODE. By these rules, the plug shall be filled with tin which has a melting point between 400 and 500 deg. Fahr. The tin shall be renewed once each year. The least diameter (Fig. 309) of the fusible metal in the plug shall not be less than 0.5 in. when the boiler pressure is less than 175 lb. per sq. in. If the pressure is greater than 175 lb. per sq. in., or if the plug is for insertion in a tube, the least diameter

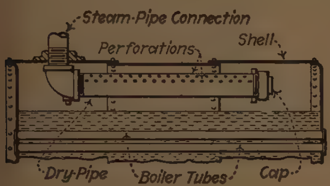


FIG. 310.

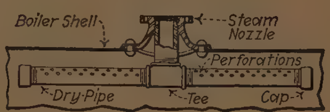


FIG. 311.

FIG. 310.—Dry pipe in horizontal return-tubular boiler. (The dry pipe shown is not drawn to scale. Its size is somewhat exaggerated to better show constructional details. The aggregate area of the holes for steam entrance into the dry pipe, should be at least equal to the area of the steam connection to the boiler. Several ½-in. holes should be bored in the bottom of each dry pipe, near its ends, to provide drainage.)
FIG. 311.—A double-ended dry pipe.

of the fusible metal may be 0.375 in. The location of the fusible plug in a horizontal return tubular boiler shall be in the rear head, not less than 2 in. above the upper row of tubes, as measured from the line of the upper surface of the tubes to the center of the plug. The plug shall project not less than 1 in. (Fig. 309) inside the boiler plate. The locations for fusible plug in boilers of various types are given in A.S.M.E. CODE, Par. 430.

369. A dry-pipe (Figs. 310, 311, 312, and 43) is a perforated or slotted pipe attached to the interior orifice of the steam-outlet nozzle of a boiler. Its function is to intercept water which is entrained with the liberated steam bubbles. The entrained water is thus prevented from passing with the steam through the outlet nozzle. It flows from the dry-pipe through drain holes back to the water space of the boiler.

NOTE.—An arrangement of flat surfaces which performs the function of a dry-pipe is shown in Fig. 313. Reversal of the steam-flow around the lip of the inverted disc causes precipitation of the entrained moisture

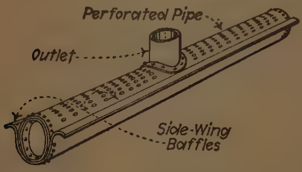


FIG. 312.—Perforated dry-pipe with side wing baffles.

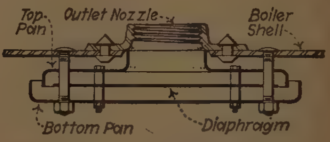


FIG. 313.—Baffle-plate steam-separating device.

in the pan beneath. From the pan it flows back to the water space of the boiler. A dry-pan is shown in Fig. 67. The space for inflow of steam between the top of the pan and the boiler shell is about 0.5 in. deep. Dry-pipes or pans, interior separators, and the like may be made of cast iron, wrought iron, steel, copper or brass. A galvanic action may result from the use of copper or brass. This is objectionable.

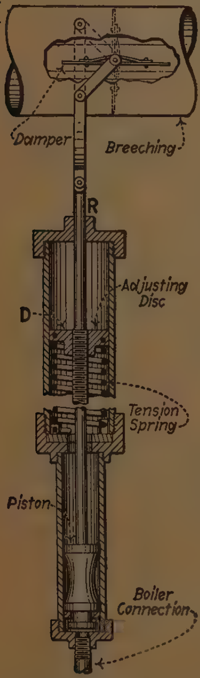


FIG. 314.—A steam-operated damper regulator.

370. A Dry-pipe Should Be Of Ample Length (Fig. 312).—This is advantageous in preventing priming which might otherwise result from forced firing. Priming might attend forced firing by reason of the violent boiling of the water directly beneath the outlet nozzle. A dry-pipe extending the full length of the boiler shell, virtually distributes the area of outlet along this distance. It thereby obviates crowding of the escaping steam bubbles directly beneath the outlet nozzle.

371. The combined areas of the perforations or slots in dry-pipes should be equal to about twice the area of the orifice in the outlet nozzle.

372. A damper regulator (Fig. 314 and 315) is a device for automatically adjusting, in accordance with the draft requirements, the position of the flue or chimney damper of a boiler installation. It may be operated by hydraulic pressure (Fig.

315), direct steam pressure (Fig. 314), or by the action of a thermostat.

EXPLANATION.—In Fig. 314 the boiler pressure acts, through an intervening body of water in the connecting pipe, beneath the piston. When the steam pressure rises, the piston is pushed upward. The damper is thus partially closed. When the steam pressure falls, the piston moves downward, and the damper opens accordingly.

In Fig. 315 the boiler pressure acts beneath a diaphragm, *D*. When the pressure rises, the diaphragm buckles up. Through the lever arm it opens the water-control valve. Water under pressure is thus admitted beneath a piston in the water cylinder, *C*. A chain, which connects the piston rod with the damper, is slackened by the upward movement of the piston. Then the damper partially closes by its own weight. When the steam pressure falls, the water outlet valve, *V*, is opened by the action of the diaphragm and lever arm. The resulting downward movement of the piston, transmitted through the damper chain, pulls the damper open.

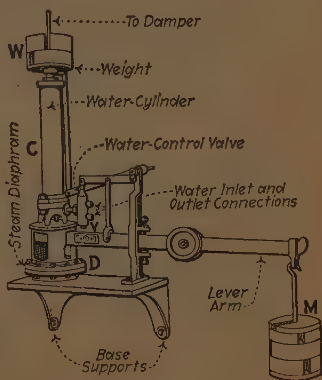


FIG. 315.—A hydraulically operated automatic damper regulator. (Ruggles-Klingeman Mfg. Co.)

NOTE.—The effect of automatic damper regulation on the economy of boiler operation is explained in Div. 14.

373. A feed-water regulator (Figs. 316, 317 and 318) is a device which automatically controls the flow of feed-water to a boiler.

374. Feed-water regulators are of two principal types, as follows: (1) *Those which maintain a constant water-level in the boiler.* (2) *Those which allow a considerable variation in the quantity of water contained in the boiler.* With the latter type of regulator, the water-level is permitted to fall to a definite extent when sudden heavy loads are thrown on the boiler, and is permitted to rise to a definite extent during intervening light-load periods.

375. The advantages claimed for automatic feed-water regulation are principally as follows: (1) *Accidents on account of either high or low water are avoided.* (2) *Local stresses, on account of contractions due to intermittent injections of large*

quantities of cool water, are avoided. (3) *Loss of effectiveness of feed-water heating apparatus, on account of intermittent*

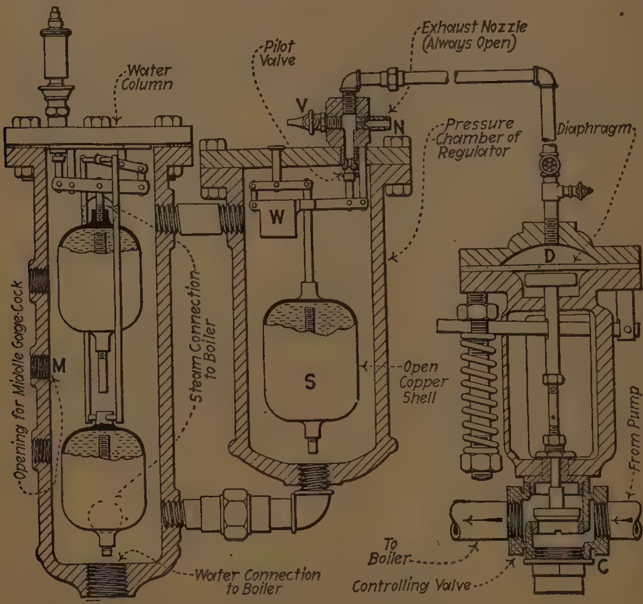


FIG. 316.—Kitts feed-water regulator.

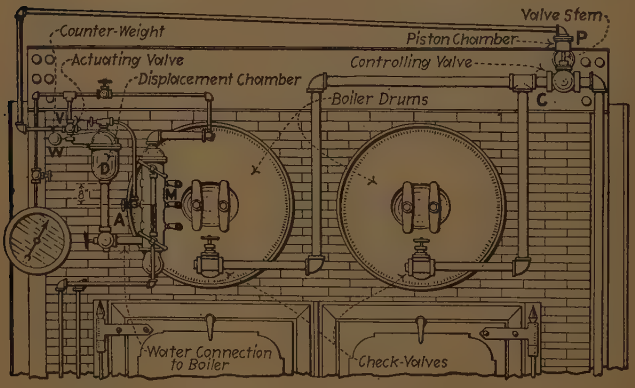


FIG. 317.—Vigilant feed-water regulator attached to water-tube boiler.

rushes of cool water, is avoided. (4) *Loss of furnace economy, on account of the irregular firing which an intermittent feed*

makes necessary is avoided. (5) *The ability of the boiler to deliver dry steam is fully realized.*

376. Feed-water Regulators Operate In Conjunction With The Governing Devices Of Feed Pumps.—The regulator increases or diminishes the opening through a controlling valve (Figs. 316, 317 and 318) in the water feed-pipe. Restricting the opening, causes the pressure in the feed-line, between the pump piston and the controlling valve, to increase. The pump governor, which is constantly in communication with the feed-line, responds to this increase of pressure by throttling the flow of steam to the pump. This stops the pump or

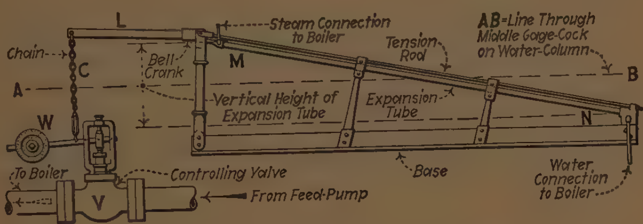


FIG. 318.—The Copes feed-water regulator.

causes it to run at a diminished speed. When the regulator enlarges the opening through the controlling valve, the pressure in the feed-line momentarily falls. The pump governor immediately responds by opening the steam valve, thus causing the pump to speed up.

NOTE.—For descriptions of pump governors, see the Author's STEAM POWER PLANT AUXILIARIES AND ACCESSORIES.

EXPLANATION.—The gravity-type regulator in Fig. 316 operates as follows: When the water-level falls below the middle gage cock, *M*, the water-filled copper shell, *S*, likewise drops. By this action the pilot valve, *V*, is closed and the diaphragm, *D*. of the controlling valve is relieved of pressure through the exhaust nozzle, *N*. The pressure of the feed water, beneath the disc of the controlling valve, *C*, being thus unopposed, forces the disc up, permitting feed water to flow into the boiler. As the water rises, it, assisted by counterweight, *W*, buoys up the copper shells, *S*. By this action, the pilot valve, *V*, is opened and steam pressure is admitted above the diaphragm, *D*. The disc of the controlling valve, *C*, is thus forced downward, shutting off the feed water

The gravity-type regulator in Fig. 317 operates as follows: When the water level falls below the middle gage cock, *M*, the connection *A* is

uncovered. Steam then enters and fills the displacement chamber *D*. A weight inside chamber, *D*, falls and thus raises the counterweight, *W*, By this action, the actuating valve, *V*, is adjusted to give an opening to the atmosphere from the piston-chamber, *P*. There now being no pressure above the piston to oppose the pressure of the water beneath the disc of the controlling valve, *C*, the valve will open and permit feed water to flow into the boiler. When the water rises above the connection, *A*, the displacement chamber, *D*, is again filled with water. The inside weight is thus buoyed up. The counterweight falls and reverses the position of the actuating valve, *V*. By this action, steam pressure is admitted to the piston chamber, *P*. The piston then forces the valve disc toward its seat and shuts off the feed water.

With the thermostatic feed-water regulator in Fig. 318, the water level is, normally, within the vertical height of the expansion tube, *MN*. Assume the water level to be coincident with the line *AB*, through the middle gage cock. As the water level falls and exposes more of the tube surface to the heating effect of the steam, the tube expands and increases correspondingly in length. This action, transmitted through the bell-crank lever, *L*, and attached chain, *C*, raises the weighted lever, *W*, and so opens the control valve, *V*. As the water level rises, the temperature of the tube decreases. The tube thus shortens. Thereby it permits closure of the controlling valve, *V*, by the weighted lever.

377. A steam-flow meter (See frontispiece) is an instrument for measuring the quantity of steam flowing through a pipe. This indicating instrument simply indicates the quantity of steam, in pounds per hour, flowing at any instant. The recording steam-flow meters draw a continuous graphic record indicating the quantity of steam, in pounds per hour, which flows at any instant during an extended interval of time. The simple indicating instrument is often used as a boiler accessory. When a steam-flow meter is connected to the steam-outlet of each boiler in an installation, the work of evaporation performed by each boiler, when all of them are working in unison, may be definitely known.

NOTE.—For a discussion of steam-flow meters, see the author's PRACTICAL BOILER ROOM ECONOMY.

378. The tools needed for handling fires in an ordinary hand-fired boiler plant are the following: (1) *A firing shovel or scoop.* (2) *A slice bar.* (3) *An ash-hoe.* (4) *A coal-pick.* (5) *A poker or clinker hook.* (6) *A rake.* (7) *A wheelbarrow.*

NOTE.—The necessary furnishings of a boiler room ordinarily include a rubber hose, a ladder, hammers and wrenches, water buckets, and a kerosene torch.

379. The firing shovel or scoop, (Fig. 319) is made of sheet steel. The width is usually from 13 to 14 in. The

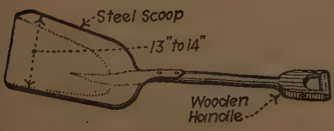


FIG. 319.—A coal scoop.

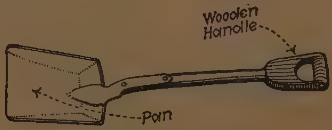


FIG. 320.—Ordinary shovel for use in boiler plant.

handle should, ordinarily, be more nearly parallel with the bottom than is usual with scoops for other purposes. The type of furnace that is being fired and the stature of the fireman may, however, modify this requirement. The scoop will hold about 10 lb. of coal.

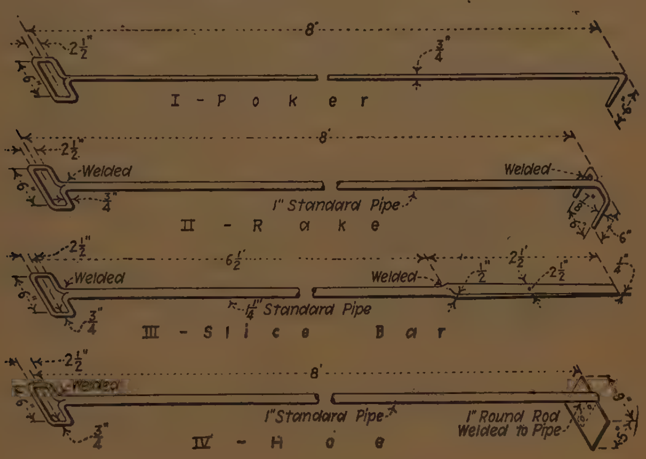


FIG. 321.—Fire tools.

NOTE.—An ordinary sand or excavating shovel (Fig. 320) should be provided for general use about the plant.

380. The slice bar (Fig. 321—*III*) is used for lifting the fire-bed lightly from the grate, so as to clear the air spaces. It is also employed for breaking up masses of clinker pre-

paratory to cleaning the fires and to stir and break up beds of caking coal. The length of a slice bar may be from 7 to 10 ft., depending on the length of the grate.

381. The ash hoe (Fig. 321) is used for cleaning the furnace.

382. The poker or clinker-hook (Fig. 321) is used for poking the fire and for loosening and hooking out small clinkers.

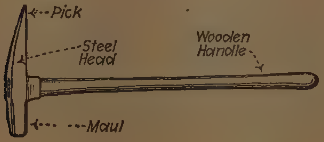


FIG. 322.—Coal pick for use in boiler room.

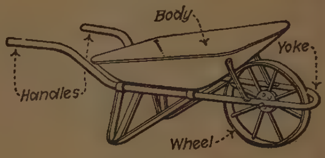


FIG. 323.—Coal-and-ash-barrow for boiler room.

383. The rake (Fig. 321) is used for leveling the fuel bed and for pulling out large masses of clinker.

384. The coal pick (Fig. 322) is used for picking out and breaking lumps of coal to a suitable size for firing.

385. The wheelbarrow (Fig. 323) should be of steel or iron construction throughout. It is needed mainly for conveying coal and ashes.

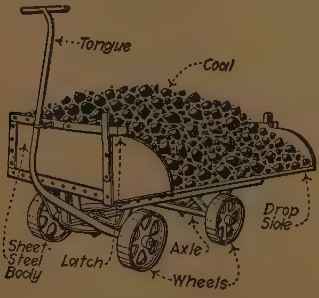


FIG. 324.—Coal truck for boiler plant.

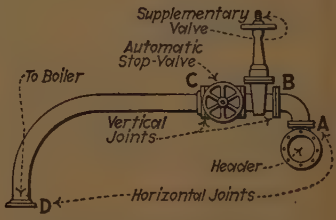


FIG. 325.—An approved form of steam-outlet piping for a boiler.

NOTE.—Coal trucks or buggies (Fig. 324) are a convenience in many plants. They are needed where the coal must be hauled from bunkers which are remote from the furnaces. The truck may have a capacity of about 1000 lb., or more. The bottom of it should be free from projections, such as rivet-heads, against which the edge of a scoop may strike.

386. The branch live steam piping which connects a boiler with the main header should be erected with a view to

avoiding excessive stresses during erection and those due to subsequent expansion and contraction. The flange unions should be so arranged relative to one another that expansion and contraction in the lengths of pipe will cause rotation or

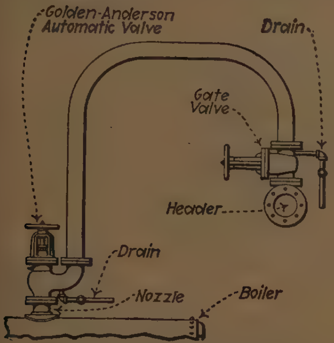


FIG. 326.—Boiler steam-outlet pipe in form of U-bend.

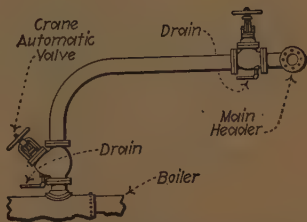


FIG. 327.—Boiler steam-outlet piping with rigid header connection.

swinging movements about the axes of the joints. This is best realized (Fig. 325) in a triple-swing connection.

NOTE.—A triple-swing connection (Fig. 325) must have a horizontal, *A*, and two vertical joint faces, *B* and *C*, at one end of the connection.

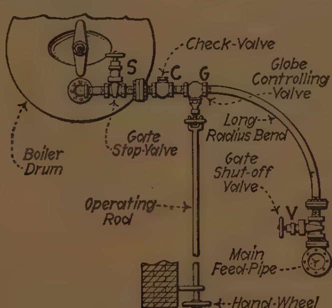


FIG. 328.—Branch feed pipe.

387. A drain pipe should be connected to the body of the automatic non-return valve (Fig. 326 and 327) in every case where the piping is such that water resulting from condensation of steam coming from the main header will collect above the valve disc when the latter is firmly seated.

388. The arrangement of the feed piping (Fig. 328) should be such as to afford convenience in regulating the feed and assurance against trouble on account of obstructions lodging in the pipe. The main feed pipe may be of iron, but the branches to the boilers should be of brass. Brass piping

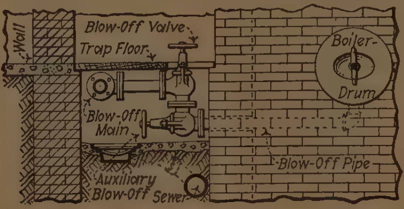


Fig. 329.—Blow-off connection for low-set boiler.

is recommended for two reasons: *It is less affected by corrosive agents in the feed-water than is iron pipe.* (2) *There is less tendency for scale-forming impurities to cling to its surfaces.*

389. The feed-piping fittings, such as elbows, tees and flanged unions, should be extra heavy and of cast iron. If,

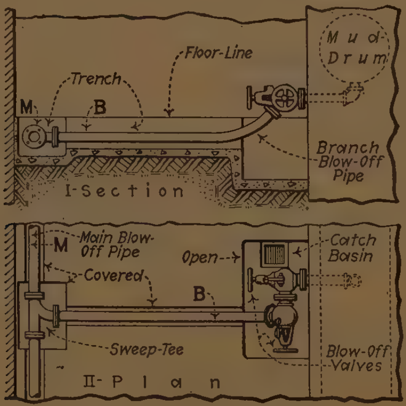


Fig. 330.—Blow-off branch.

however, there is a fitting, as an elbow, between the stop valve and boiler, it should be of brass extra heavy. Water-hammer from some unforseen cause might develop in the piping while the boiler is in operation and a cast-iron fitting might break under the strain. In the general design of a feed-water-

piping system, long radius bends should be used, whenever possible, instead of short right-angled fittings.

NOTE.—See A.S.M.E. CODE, par. 317 for feed-pipe valve requirements. In Fig. 328, *S*, *C* and *G* are required by the CODE. *V* is installed so that *C* and *G* may be repaired or reground without shutting down.

390. Systems of Blow-off Piping Figs. 329, 330 and 331 are variously planned. Space limitations are often the deciding factor in adapting a plan of installation. A good method (Fig. 330) for use where the space between the floor and the horizontal lead from the boiler is restricted, is to run the main, *M*, at some distance from the back end of the boiler. This is necessary to insure flexibility in the connections. If the main pipe, *M*, in Fig. 330 were laid in close to the boiler, the vertical connection would be too short and rigid for safety. The connection, *B*, between the branch and the main should always be through a sweep tee. This minimizes the endwise thrust of the branch, and consequently the strain on the connections, when the blow-off valve is opened.

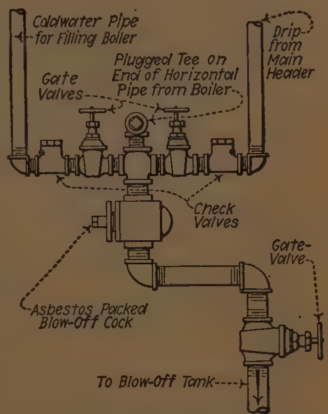


FIG. 331.—Blow-off pipe with filling pipe and header drain attached.

QUESTIONS ON DIVISION 11

1. What are boiler accessories?
2. What do you regard as the least number of accessory appliances with which a boiler can be safely operated? Name them.
3. Define a dead weight safety valve; a weighted lever safety valve; a spring-loaded safety valve.
4. What is the essential difference between the loading of a dead weight safety valve and that of a weighted-lever safety valve?
5. In what respects does the spring-loaded safety valve more adequately meet the requirements of boiler service than does the weighted-lever safety valve?
6. Upon what general principle of construction does the prompt action of spring-loaded safety valves depend?
7. Which would give the more satisfactory service as a safety valve—an ordinary valve disc loaded by means of a spring, or an ordinary valve disc loaded by means of a weighted lever?

8. A spring-loaded safety valve opens when the pressure in the boiler is 150 lb. per sq. in. and continues to blow until the pressure is 130 lb. What should ordinarily be done to cause it to close at, say, 142 lb.?

9. What metals should be used in the discs and seats of safety valves? Why will not iron or steel suffice for this purpose?

10. What may cause chattering of safety valves?

11. What precautions should be observed in the piping of safety valves?

12. What is an accumulation test?

13. What precautions should be observed as preliminary to an accumulation test?

14. What considerations govern in determining whether one or two safety valves shall be used on a boiler?

15. What factor determines the requisite relieving capacity of a safety valve? What is the value of this factor for a water-tube boiler? For any other type of boiler?

16. What factors mainly govern in making a choice of location for the feed water inlet to a boiler?

17. How should the feed-water connection to a horizontal return tubular boiler be arranged?

18. What might be considered an inhibitive defect of the spray method of feeding a boiler?

19. What advantage would a spray-feed secure? Would not this advantage be multiplied by the disadvantage of the device?

20. What is a check valve? What purpose does it serve in a feed-line?

21. What good purposes are served by automatic stop valves in the steam-outlet connections of boilers?

22. How may automatic non-return stop valves conserve the economy of a boiler plant?

23. What are the advantages of installing an ordinary stop valve in conjunction with an automatic stop valve in the steam-outlet connection of a boiler?

24. What is the basic pressure in the reading of an ordinary steam gage?

25. What is the operating principle of an ordinary steam gage?

26. What harm would result from admitting steam directly to a steam gage? How may this be prevented?

27. What is a water column? In what kind of boiler installation is it indispensable? For what types of boilers is it unnecessary?

28. In the installation of a water column, how should its proper height be gauged?

29. What should be the minimum size of the steam and water connections of a water column in any case?

30. What are the restrictions of the A.S.M.E. Code in regard to valves in water-column connections?

31. What is the objection to tight-closing automatic valves in the glass water gage connections?

32. What should be the height, above the tubes, of the lower valve of the glass water gage on a horizontal return tubular boiler? What should be the location of this valve on a vertical fire-box boiler? On a horizontal fire-box boiler?

33. How do high- and low-water alarms operate?

34. What benefit results from periodic blowing off of the surface water in a boiler?

35. What should be the maximum size of the surface blow off piping in any case?

36. What benefit results from periodic blowing down of the water in a boiler?

37. Why is it necessary to shield the bottom blow-off pipe from the direct action of the fire?

38. What are the minimum and maximum pipe sizes permissible for bottom blow-off connections? Why are these restrictions necessary?

39. What advantage is there in feeding a boiler through the blow-off pipe? What disadvantage?

40. What materials should be used in the boiler blow-off fittings?

41. What are the requirements of the A.S.M.E. Code regarding blow-off valves?

42. Why are ordinary globe and gate valves ill-adapted for blow-off service?

43. What is the purpose of a blow-off tank?

44. Of what are sooty deposits in and on boiler tubes composed?
45. How may soot be removed from fire tubes? From water tubes?
46. What are the advantages of permanently attached soot blowers?
47. What percentage of saving may be realized by systematic soot-blowing in a boiler plant?
48. What are the operating principles of mechanical scale removers?
49. What is the object of inserting fusible plugs in boilers?
50. What are the requirements of the A.S.M.E. CODE regarding the location of fusible plugs in horizontal return-tubular boilers?
51. What is the standard fusible metal for use in fusible plugs?
52. What is the function of a dry-pipe? How is this function performed?
53. How may a well-designed dry-pipe prevent priming?
54. Through what mediums is the energy for operating damper regulators applied?
55. What are the two principal types of feed-water regulators?
56. What advantages are claimed for automatic feed-water regulation?
57. What is a steam-flow meter?
58. What is the advantage of fitting each boiler in an installation with a steam-flow meter?
59. What tools and equipment are necessary for handling the fires in an ordinary hand-fired boiler plant?
60. What should be the foremost consideration when planning the branch piping from a boiler to the main steam header?
61. What is a triple-swing connection?
62. Why should automatic non-return stop valves be fitted with drain pipes?
63. What are the advantages of using brass pipe in the feed-water lines?
64. Why is flexibility of the connections particularly essential in blow-off piping?

PROBLEMS ON DIVISION 11

1. The disc of a weighted-lever safety valve is 3 in. in diam.; the distance from the fulcrum to the center of the disc is 2.5 in.; the valve disc and stem weight 1.5 lb.; the center of gravity of the lever is 15 in. from the fulcrum; the lever weighs 6 lb.; the valve is required to blow at a pressure of 75 lb. per sq. in. At what distance from the fulcrum should a 48-lb. ball be hung?

2. A 3.5 in. bevel-seated pop safety valve opens at 120 lb. pressure per sq. in. and closes at 116 lb. The average lift of the disc is 0.1 in. What weight of steam is blown away in 40 discharges of the valves, if the average duration of the discharge periods is 4.5 min.?

3. Assuming the total length of the lever in problem (1) to be 36 in., what weight hung at its extreme end would cause the valve to open at 80 lb. pressure per sq. in.?

DIVISION 12

STEAM GENERATION AND SUPERHEATING

391. Heat must be Transmitted from the Fire in the Furnace to the Water in the Boiler when Steam is to be Generated. Three methods (Fig. 332) of heat-transmission are utilized in getting the heat to the water. These are: (1) *Radiation.* (2) *Convection.* (3) *Conduction.*

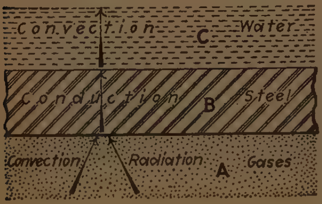


FIG. 332.—Transfer of heat from fire to water.

NOTE.—The three methods of heat-transmission enumerated in the preceding Sec. do not, necessarily, act in independent succession. It has been found that all three may operate in unison in the three stages (*A*, *B* and *C*, Fig. 332) of transmission. Methods of heat-transmission are discussed in the author's PRACTICAL HEAT.

392. The Resistance to Heat Transfer from the Fire to the Water Should be a Minimum.—Experiment has shown that a large part of such resistance is due to stagnant or quiescent gas which clings to the heating surfaces. A body of gas in this condition is a good insulator. Provision should be made for producing a rapid general movement of the gases through the combustion chamber and gas passages. Movement may thus be imparted to bodies of gas which might otherwise remain stagnant. Hence their transference of heat by convection will be improved.

NOTE.—Stagnation of furnace gases may be avoided by forcing the gases through restricted passages. This may be accomplished by means of baffles which limit the areas of the passages. The gases are thus constrained to travel a greater distance, and at a higher velocity, than they would otherwise. In locomotive, and some stationary, boilers the fire-tubes are made as small as practicability will permit. Forced or induced draft is then applied to cause the hot gases to travel at high velocity through the restricted passages thus afforded.

393. Stagnant Water Adjacent to the Heating Surface Prevents Free Flow of Heat to the Mass of Water in the Boiler. To insure adequate heating of the water, and to prevent overheating of the boiler metal, water-circulation (Fig. 333) must be provided. This is secured by a structural arrangement which permits the colder and more dense portion of the water to descend through one part of the boiler. There it displaces the hotter and less dense portion. The hotter portion is thus constrained to flow upward through another part of the boiler. The more rapid the circulation, the better the heat-transfer.

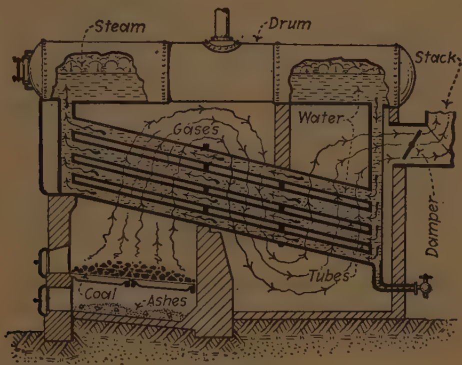


Fig. 333.—Showing water and gas circulation in B. & W. boiler.

394. Steam Bubbles resist Free Flow of Heat.—Scouring the bubbles from the interior surfaces of a boiler conduces to economy. A rapid water-circulation accomplishes this. The rapidity of circulation depends upon the height and relative densities of the downward-flowing column of cool water and the upward-flowing column of mingled hotwater and steam.

Note.—The principles of water-circulation are illustrated in the author's Practical Heat.

395. The Steam-space in a Steam Boiler is the Space above the Water Level.—The steam-space should be of sufficient volume to permit complete disengagement of the steam from the water. When the steam flows intermittently from the boiler, the steam-space should be larger than when the flow is steady.

Note.—The necessary steam-space may be computed from the steam-consumption of the prime-mover which the boiler is required to serve. When natural draft is used, the computations may, according to Parsons, be made upon the following bases: Small, slow-running engines, steam-pumps, etc., 1.0 to 2.5 cu.ft. of steam-space for each i.h.p. Medium-speed engines, 0.8 to 1.0 cu. ft. per i.h.p. Fast-running stationary engines, 0.5 to 0.8 cu. ft. per i.h. p. In boiler-design, the steam-space is often figured from the nominal rating (Sec. 403) of the boiler. The average volume of steam-space in cu. ft. per rated boiler horse power, is, for boilers of different types about as follows: (1) *Locomotive*, 0.15. (2) *Water-tube*, 0.50. (3) *Return-tubular*, 0.93. (4) *Portable*, 0.75. (5) *Cylindrical*, 2.50. (6) *Vertical*, 0.45. (7) *Scotch*, 0.55.

396. Priming and Foaming in a Boiler are Undesirable (See also note under Sec. 600).—*Priming* is entrainment of water from the boiler with the outgoing steam. *Foaming* is the formation of steam-containing bubbles on the surface of the water.

Note.—Priming may be due to insufficient steam-space. The water-surface should afford sufficient area for the steam-bubbles to ascend from the water without crowding. Forcing a boiler may cause priming.

397. The Quality of Steam is the Percentage of Water Vapor, as Distinguished from Moisture, which is Present in the Total Weight of Steam.—It is often thought of as the *dryness of the steam.* Ordinarily, a boiler delivers steam which contains from 1 to 3 per cent. of water. The quality of steam in average practice is, therefore, from about 97 to 99 per cent. The quality of steam may be determined by means of the steam-calorimeter, as described in the author's PRACTICAL HEAT.

Example.—If half the weight of steam issuing from a pipe is in the form of water-particles, the quality of the steam is 50 per cent.

398. Superheated Steam is Steam that has a Higher Temperature than Boiling Water under a Pressure equal to the Pressure of the Steam.—*Saturated steam* always has the same temperature as the boiling water from which it is generated. If heat is imparted to saturated steam, subsequent to its emergence from contact with the water, it then becomes *superheated steam.* The resulting increase of temperature is called the *degree of superheat.*

EXAMPLE.—Saturated steam at a pressure of 100 lb. per sq. in., absolute, has, as shown by the steam tables, a temperature of 327.8 deg. Fahr. If such steam passes through a superheater, and emerges therefrom at a temperature of 378.8 deg. Fahr., the superheat is 378.8 − 327.8 = 51.0 *deg.*

399. Steam is Superheated by Passing it through Piping which receives Heat in a Manner similar to that which is

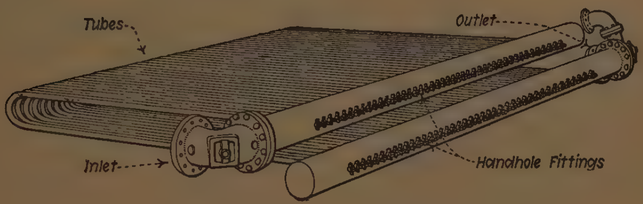


FIG. 334.—Babcock & Wilcox superheater.

observable in other parts of the Boiler.—The superheating apparatus is called a *superheater.* Superheaters are of two general types: (1) *Built-in superheaters* (Frontispiece, Figs. 71, 334 and 335). (2) *Separately-fired superheaters* (Fig. 336). The saturated steam from the boiler passes through the

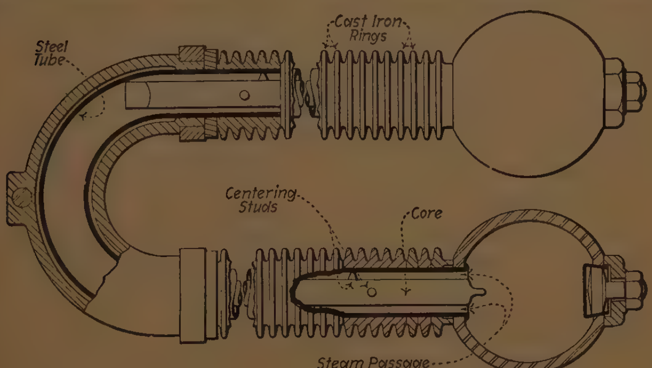


FIG. 335.—Foster superheater.

superheater, whence, in the condition of superheated steam it inters the steam main.

NOTE.—A superheater should (Hirshfeld and Barnard, HEAT-POWER ENGINEERING) fulfil the following requisites: (1) *Perfect freedom of expansion.* (2) *Ability to withstand high temperatures, high pressure, and*

sudden changes of temperature. (3) *Avoidance of screwed joints.* (4) *Non-exposure of joints to the hot gases.* (5) *Access for cleaning, externally and internally.* (6) *Means for adjusting the superheat to any desired temperature.* (7) *Automatic control of the desired temperature.* (8) *Means for by-passing the steam when the superheater is out of service.* (9) *Provision, in some cases, for flooding the apparatus with water, and for draining it.* (10) *Occupation of small space.* (11) *Low first cost.* (12) *Small expense for operation and maintenance.*

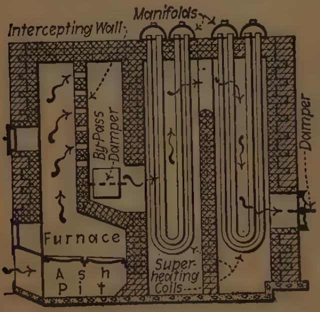


FIG. 336.—Separately fired superheater.

400. Use of Superheated Steam is Conducive, Generally, to Power plant Economy.—(1) *Steam, when superheated, acquires properties similar to those of gases.* When superheated sufficiently, the steam may expand in an engine cylinder and finally emerge therefrom as dry steam. When saturated steam is used, it ordinarily emerges as very wet steam. (2) *Superheated steam weighs less than saturated steam of the same pressure.* The volume increases rapidly as the superheat is applied. Therefore, less steam, than would otherwise be required, need be admitted to the engine cylinder for a given quantity of work. (3) *Superheated steam does not conduct heat as readily as does saturated steam.* This results in less heat being transferred by superheated steam to piping, cylinder walls, etc., than by saturated steam.

401. The saving effected by a superheater may be from about 5 to 15 per cent. Greater savings may sometimes result. In steam-turbine practice, use of superheated steam is particularly advantageous. Less wear by friction, of the turbine blades and nozzles, occurs with superheated steam than with saturated steam. Present indications point to the use in the future of higher steam pressures and more superheat than have been hitherto used.

QUESTIONS ON DIVISION 12

1. What are the three methods of heat transmission?
2. To what is the resistance to heat transmission in a boiler largely due? How may this be remedied?

3. What disadvantage results from stagnant bodies of water adjacent to the heating surfaces of boilers? How may stagnation be prevented?

4. How may the insulating effect of steam-bubbles in contact with the boiler metal be eliminated?

5. What is meant by steam-space? What values may be used in boiler design in proportioning the steam space?

6. What is *foaming? Priming?*

7. What may be the cause of priming?

8. What is meant by *steam of* 95 *per cent. quality?*

9. What is superheated steam?

10. How is steam superheated?

11. Give the requisites of an ideal superheater.

12. Why is use of superheated steam conductive to power-plant economy?

13. Why is superheated steam particularly desirable for use in steam turbines?

DIVISION 13

BOILER CAPACITIES AND RATINGS

402. The Capacities of Steam Boilers are Designated by an Arbitrary Unit Called a Boiler Horse Power.—This unit has no definite mathematical relation to the horse-power unit which is used for expressing the *rate of doing work*. It is merely an expression for the rate of evaporation of water in a boiler. It may be defined as *the evaporation of* 34.5 *lb. of water, per hr., at a temperature of* 212 *deg. fahr. into steam at the same temperature.* This is equivalent to an expenditure of 33,479 B. t. u. per hour.

NOTE.—The standard unit of boiler horse power was determined arbitrarily, in 1884, by a committee appointed by the A.S.M.E. In 1899 a committee of the A.S.M.E. decreed that a boiler which is rated in accordance with this unit should develop its rated capacity under the following conditions: (1) *When fired with the best coal ordinarily sold in the market where the boiler is located.* (2) *When fired by an ordinarily skillful fireman.* (3) *When worked without forcing the fires.* (4) *While exhibiting good economy.* It was furthermore decreed that the boiler should exceed its rated evaporation capacity by at least ⅓ when fired with the same fuel and by the same fireman as in the test of its rated capacity, but under full draft and with the fires crowded. The available draft at the damper in this case should, unless otherwise stipulated, be not less than 0.5 in. of water.

403. Boiler ratings are, in a general way, based on the A.S.M.E. boiler horse power unit of capacity. It would, however, be impracticable for a boiler manufacturer to guarantee a boiler capacity in conformity with this A.S.M.E. unit without knowing, in advance, the kind of fuel which is to be used, the arrangement of the boiler setting, the skill of the fireman, the intensity of the draft, and other variables. Hence, boilers are not usually sold, in the general market, on the basis of their A.S.M.E. boiler horse power outputs.

The common direct basis of rating is the extent of heating surface.

Note.—Experience has shown that there is a fairly definite relation for boilers of different types, between the heating surfaces (Sec. 406) and the A. S. M. E. unit of boiler capacity. The square feet of heating surface, in each type, which is necessary for the development of one boiler horse power is about as follows: (1) *Return tubular*, 12 *to* 15. (2) *Vertical fire-tube* 10 *to* 12. (3) *Locomotive*, 9 *to* 10. (4) *Scotch*, 6 *to* 8. (5) *Water-tube*, 10. (6) *Two-flue*, 10 *to* 12.

404. The modern practice in rating boilers is to assume arbitrarily for all types, that 10 sq. ft. of heating surface is sufficient for developing one boiler horse power. All power boilers are now commercially rated on this basis, as a matter of expediency.

Example.—A boiler that has 1250 sq. ft. of heating surface is rated as a 1250 ÷ 10 = 125 *horse power boiler*.

405. Boïlers are often Required to Evaporate Water at a Rate Higher than that Established by the Manufacture's Nominal Rating.—In modern power plants, boilers are often forced from 200 to 400 per cent. of the nominal rating. On peak loads the evaporation may be from 300 to over 600 per cent. of that required to develop the nominal horse power rating. (*Electrical World*, Aug. 9, 1919, p. 292.)

Note.—Forcing a boiler is not necessarily injurious to the boiler. It is usually considered good practice, if the efficiency is maintained. In locations where ground space is not available, or can be obtained only at a high price, it may be profitable to use as few boilers as possible and to realize the requisite output by forcing the plant to its utmost capacity. The cost of boilers, buildings and attendance may thus be curtailed.

406. The heating surface of a boiler is the surface which is exposed to the hot gases. In general (Gebhardt), a boiler is most efficient when the heating surface is so extended that the temperature of the gases leaving the uptake is from 75 to 150 deg. fahr. above the temperature corresponding to the steam pressure being carried by the boiler.

Note.—Boiler heating surface may be either *water-heating surface* or *superheating surface*. Water-heating surface is contiguous to water

on the inner surface of the boiler. Superheating surface is contiguous to steam in the inner surface of the boiler. The water-heating surface is the more effective in transmitting heat to the interior of the boiler.

407. In computing the heating surfaces of boilers only the surface exposed to the fire should be considered. The A.S.M.E. advocates using the inside diameters of fire-tubes and the outside diameters of water-tubes as bases of computation for boiler tube heating surfaces.

NOTE.—Only water-heating surface should be considered in computations. Surfaces which are covered by brickwork, or which are below the plane of the furnace grate, should, when not exposed to fire, be disregarded. When a boiler is cylindical, with masonry coming tangent to it on both sides, it is assumed that only 3/8 of the cylindrical surface is effective as heating surface, inasmuch as the gases will be stagnant along the sides. Tube sheet and water-leg areas are sometimes neglected. Boiler manufacturers often base their fire-tube heating-surface computations on the outside diameters of the tubes.

EXAMPLE.—The return tubular boiler shown in Fig. 36. is 14 ft. long, 42 in. in diam., and has thirty-four 3-in. tubes. Since the brickwork is corbeled off from the shell as shown, one-half the circumferential area of the shell is effective heating surface. What is the nominal or commercial horse power rating at the boiler? SOLUTION.—The heating surface of the shell = (0.5 × *diam. in in.* × 3.14 × *length in ft.*) ÷ 12 = (0.5 × 42 × 3.14 × 14) ÷ 12 = 77 *sq. ft.* The inside diam. of a 3-in. tube is 2.782 in. The heating surface of the tubes = (*inside diam. in in.* × 3.14 × *length in ft.* × *number of tubes*) ÷ 12 = 2.782 × 3.14 ×14 × 34) ÷ 12 = 347 *sq. ft.* The total heating surface = 77 + 347 = 424 *sq. ft.* The commercial rating is, therefore, 424 ÷ 10 = 42.4 *rated boiler h.p.* Tube-sheet area is neglected; see Note under Sec. 407.

EXAMPLE.—The water-tube boiler shown in Fig. 67 has 67 tubes. The tubes are of 3-in. external diam., and 16 ft. long. The drum is 30 in. in diam. One-half the circumferential area of 16 ft. length of the drum is effective heating surface. The water-legs are 64 in. wide and 42 in. high. What is the nominal or commercial horse power rating of the boiler? SOLUTION.—The heating surface of the tubes = (*outside diam. in in.* × 3.14 × *length in ft.* × *number of tubes*) ÷ 12 = (3 × 3.14 × 16 × 67) ÷ 12 = 842 *sq. ft.* The heating surface of the drum = (0.5 × *diam. in in.* × 3.14 × *length of exposed area in ft.*) ÷ 12 = 0.5 × 30 × 3.14 × 16) ÷ 12 = 62.8 *sq. ft.* The heating surface of the water-legs = 2 [(*Width in in.* × *height in in.*) − (*Outside tube-diam. in in., squared,* × 0.79 × *number of tubes*)] ÷ 144 = 2 [(64 × 42) − (3^2 × 0.79 × 67)] ÷ 144 = 30.8 *sq. ft.* The total heating surface = 842 + 62.8 + 30.8 = 935.6 *sq. ft.* The commercial rating is, therefore, 935.6 ÷ 10 = 93.6 *boiler h.p.*

QUESTIONS ON DIVISION 13

1. What is the name of the standard unit by which the capacity of a boiler is measured? What is the value of this unit?

2. Upon which basis are the horse powers of boilers nominally rated?

3. What is meant by *forcing a boiler?*

4. What circumstances may require sporadic forcing of the boilers in a power plant? Continuous forcing?

5. What is *water-heating surface*? *Superheating surface?*

6. Explain the method of computing the heating surface of a water-tube boiler. Of a fire-tube boiler.

PROBLEMS ON DISCUSSION 13

1. A horizontal return-tubular boiler has 40 tubes. The external diam. of the tubes is 3.5 in. The thickness of their walls is 0.12 in. The shell is 16 ft. long and 52 in. in diam. The side walls are tangent to the shell. What is the horse power rating of the boiler?

DIVISION 14

FUELS

408. The Principal Steam-fuels are Coal and Petroleum. Of these, coal is the most common. The fuels herein enumerated, and others, are discussed more fully in the author's Practical Heat.

409. The calorific values of the principal steam fuels, in B. t. u per pound of air-dry fuel, are approximately as follows: (1) *Anthracite from* 12,800 to 14,500. (2) *Semi-anthracite, from* 12,000 *to* 14,400. (3) *Semi-bituminous, from* 14,200 *to* 15,200. (4) *Bituminous, from* 9,000 *to* 13,500. (5) *Sub-bituminous, about* 11,000. (6) *Lignite, from* 9,000 *to* 12,000. (7) *Petroleum from* 18,000 *to* 21,000. See the Author's Practical Heat for more complete information.

Note.—A Fuel Is "Air-dry" after it has been spread out in a thin layer and exposed to the air of a warm room for several hours.

Note.—Tests To Determine The Relative Calorific Values Of Fuel Oil And Coal indicate that 1 lb. of oil is the equivalent of about 1.37 lb. of bituminous or 1.67 lb. of anthracite coal. A maximum evaporation of about 15 to 16 lb. of water per lb. of fuel has been obtained with oil as against about 11.5 to 12 lb. of water per lb. of combustible with coal.

410. The different classes of coal are: (1) *Anthracite.* (2) *Semi-anthracite.* (3) *Semi-bituminous.* (4) *Bituminous.* (5) *Sub-bituminous.* (6) *Lignite.*

411. Anthracite is commonly called *hard coal.* It is very dense. Its specific gravity is high. It has a metallic luster. It burns with a short yellowish-blue flame and without smoke. It is largely carbon. Analyses of various grades (air-dry) show an average of about 83.5 per cent. fixed carbon, 3.2 per cent. volatile matter, 10.5 per cent. ash and 2.8 per cent. moisture.

412. Table.—Commercial Sizes Of Anthracite.

Commercial or trade name	Size of standard square mesh, in inches.	
	Through	Over
Broken	4	2¾
Egg	2¾	2
Stove	2	1⅜
Chestnut	1⅜	¾
Pea	¾	½
Buckwheat No. 1	½	¼
Buckwheat No. 2	¼	⅛
Buckwheat No. 3	⅛	1/16

NOTE.—Boiler-fuel anthracite is generally one of the last three sizes.

413. Semi-anthracite is less hard than anthracite. It is less dense, ignites more readily, and is of somewhat duller metallic lustre. An analysis (air-dry) may show about 83.0 per cent. fixed carbon, 9.4 per cent. volatile matter, 6.3 per cent. ash and 1.3 per cent. moisture.

414. Semi-bituminous coal resembles anthracite more closely than it does bituminous coal. It is lighter than anthracite and ignites more readily. It is a very desirable steam-coal. Its combustion produces intense heat and very little smoke. It leaves little or no clinker. Analysis (air-dry) of an average grade may show 73 per cent. fixed carbon, 17 per cent. volatile matter, 2 per cent. moisture, and 8 per cent. ash.

415. Bituminous or soft coal appears in a wide diversity of grades and sizes. It is difficult to form precise distinctions between the different grades. The color ranges from very black to brown. The more dense varieties show a resinous lustre. Those less dense show a silky lustre. Bituminous coals generally burn with a yellow flame and much smoke. They may be divided into two general classes: (1) *Caking*. (2) *Non-caking*.

NOTE.—A CAKING OR COKING COAL appears to melt and run as a fluid when thrown on the burning fuel-bed. Thus it may spread over the entire furnace area, swell and blister. The blisters burst and emit

gas, which burns with a bright yellow or red flame. Such coal is usually well suited for gas-making. This is due to the volatile hydrocarbons which it contains.

A Non-caking Non-coking or Free-burning Coal does not melt and run into a crust. With this coal, the fires are easily kept clean.

416. Cannel coal is a non-caking bituminous coal. It kindles easily and burns freely with a bright flame, similar to a candle flame. From this circumstance it derives its name. It contains about 50 per cent. volatile matter. This renders it valuable for gas-making. Its structure is very compact. It has a dull lustre. When a lump of cannel coal is broken, the fracture will appear to occur along no definite cleavage line.

417. Sub-bituminous coal is a lower grade of fuel than bituminous coal. Its fuel-value is intermediate to those of the true bituminous coals and the lignites.

418. Lignite is, apparently of more recent fossil origin than the various coals. It ranges in color from brown to black. It is of woody texture. It is very soft. When exposed to the weather it readily absorbs moisture, and disintegrates by crumbling. Generally, it must be burned in the locality where mined. This is due to its tendency to break up in transportation. Dry lignite may contain over 40 per cent. volatile matter and 7 per cent. ash.

Note.—Newly mined lignite may contain 35 per cent. of moisture. Some anthracites and bituminous coals contain as low as 2 per cent. of moisture.

419. The sizes and grades of the different bituminous coals are not universally standardized. The coal fields of the United States are approximately separated into two grand divisions—the Eastern and the Western. In each of these a separate size-and-grade schedule is recognized.

Note.—The following classification of bituminous coals according to size and grade is adapted from Mark's Mechanical Engineer's Handbook.

1. Eastern Bituminous Coals.—(*a*) *Run of mine coal* is the unscreened coal as taken from the mine. (*b*) *Lump coal* is that which passes over a bar screen with openings 1¼ in. wide. (*c*) *Nut coal* is that which passes through a bar screen with 1¼-in. openings, and over one with ¾-in. openings. (*d*) *Slack coal* is that which passes through a bar screen with ¾-in. openings.

2. Western Bituminous Coals.—(*a*) *Run of mine coal* is the unscreened coal as taken from the mine. (*b*) *Lump coal* is divided into 6-in., 3-in., and 1¼-in. *lump*. These sizes are determined by the diameters of the circular openings over which the respective grades will pass. There is also 6 × 3-in. *lump* and 3 × 1¼-in. *lump*. These sizes depend on passage of the coal through a circular opening whose diameter is expressed by the larger figure and over one whose diameter is expressed by the smaller figure.

(*c*) *Nut coal* is divided into 3-in. *steam-nut*, which passes through an opening 3 in. in diam. 1¼-in. *nut*, which passes through a 1¼-in. diam. opening and over a ¾-in. diam. opening; ¾-in. *nut*, which passes through a ¾-in. diam. opening and over a ⅝-in. diam. opening. (*d*) *Slack coal* is that which passes through a ⅝-in. diam. opening. (*e*) *Washed sizes* are those which pass through or over circular openings as given in table 420.

420. Table Showing Washed Sizes of Western Bituminous Coal.

Size number		1	2	3	4	5
Diameter hole, inches	Through	3	1¾	1⅛	¾	¼
	Over	1¾	1⅛	¾	¼	0

Petroleum (See also Div. 18) is a mineral oil. It is composed of a series of hydrocarbons in various proportions. Crude petroleums from different fields show different compositions. In general, the oil is composed of from about 84 to 85 per cent. carbon, and 11.5 to 14.5 per cent. hydrogen and a small percentage of other substances. Oil fuels are discussed more fully in the author's Practical Heat.

422. Gases, natural and artificial, are treated in the author's Practical Heat.

QUESTIONS ON DIVISION 14

1. State the average calorific values for the principal steam fuels.
2. What is the relative calorific value of coal as compared with oil?
3. What is anthracite?
4. What sizes of anthracite are most commonly used for steaming purposes?
5. What are the characteristics of semi-anthracite? Bituminous coals? Semi-bituminous coals? Sub-bituminous coals? Lignite?
6. Explain what is meant by (1) caking coal, (2) non-caking coal, (3) cannel coal.
7. Discuss the sizes and grades of bituminous coal.
8. What is the general composition of petroleum?

DIVISION 15

COMBUSTION AND FIRING

423. The combustible in a steam-fuel comprises those portions which undergo combustion or burning. It is commonly regarded as the sum total of the constituents which remain after deduction of the moisture and ash. These "combustible" constituents, generally, are carbon, hydrogen and sulphur.

424. Combustion may be defined as the chemical union, at a rate sufficiently rapid to produce a high temperature, of oxygen with the combustible in a fuel. This subject is treated fully in the author's PRACTICAL HEAT.

425. The oxygen necessary for combustion is obtained from the air. Air is composed, by weight, of about 23 per cent. oxygen and 77 per cent. nitrogen. By volume, the proportions are 21 per cent. oxygen and 79 per cent. nitrogen. Nitrogen is an inert gas. Hence, it does not combine with other substances to produce combustion. Small quantities of other gases are present in air. These, however, do not affect combustion.

426. The process of combustion in a boiler furnace is very complicated. But regardless of what chemical reactions occur, the combustion should, in general to insure maximum economy, be complete. The products of complete combustion are: (1) *carbon dioxide gas*, CO_2. (2) *Water*, H_2O. (3) *Nitrogen gas*, N_2. (4) *A small quantity of sulphurous acid gas*, SO_2. If combustion is incomplete, the products may contain some *carbon monoxide gas* (CO). There will then be a correspondingly smaller quantity of CO_2. Hence, the completeness of combustion may be gaged quite accurately from the amounts of CO and CO_2 in the discharge gases.

NOTE.—Usually, 10 to 15 per cent., by volume of CO_2 indicates efficient combustion. In practical boiler operation, by using apparatus which indicates the CO_2 content in the discharge gases, the completeness

of the combustion may be judged. Furnace economy can then be controlled accordingly. See author's PRACTICAL HEAT.

427. The quantity of air actually required for the combustion of coal is commonly considered to be about 12 lb. for each pound of coal.

NOTE.—It has been determined (FINDING AND STOPPING WASTE IN MODERN BOILER ROOMS, *Harrison Safety Boiler Works*) that the quantity of air requisite for the combustion of 1 lb. of coal may vary from 7 to 11.2 lb. Hence, it is suggested that the *air-supply to a boiler furnace be expressed as pounds of air per* 10,000 *B.t.u.* On this basis, combustion of coal requires about 7.5 lb. of air per 10,000 B.t.u. generated.

428. The Quantity of Air Actually required for Combustion is always in Excess of the Quantity Theoretically Required.—This is due to the impracticability of securing, if no more than the theoretically requisite quantity of air were admitted to the furnace, a perfectly adequate mixture of the oxygen with the combustible. Usually, from 30 to 50 per cent. excess air should suffice to insure complete combustion. An excess of 200 per cent., and even 400 per cent., is not uncommon. This results in great loss, since these inordinate volumes of excess air act only to carry heat from the furnace.

429. The Requisites for Proper Combustion. (PRINCIPLES OF COMBUSTION IN THE STEAM BOILER FURNACE, A. D. Pratt) are:

1. The admission of an air supply such as will assure sufficient oxygen for complete combustion.
2. Since complete combustion is not, of necessity, efficient combustion, it must be secured without permitting dilution of the products of combustion with excess air. It follows then, that:
3. The air supply should be admitted at the proper time and in such a manner that the oxygen of the air will come into free and intimate contact with the combustible substances in the fuel. In the case of solid fuels this means not only into contact with the solid particles of the oxidizable substances, but also with the combustible gases as they are distilled from the fuel.
4. The gases must be maintained at a temperature at or above their ignition point until combustion is complete. Theoretically, the most efficient combustion is that resulting in the maximum temperature possible. In practice, there are, frequently, factors which, from the standpoint of commercial operating efficiency, make it advisable to

keep furnace temperatures somewhat below those which could be obtained were this the sole factor involved.

5. An additional requirement, which has to do with the physical rather than the chemical aspect of combustion, is that proper provision must be made for the expansion of the gases during the period of their combustion.

430. The Efficiency of Combustion is Determined solely from the Chemical Changes that occur in the Burning Combustible.—It is independent of all considerations with respect to the ability of the boiler to absorb the heat which is generated.

NOTE.—Certain physical and mechanical factors, involving details both of furnace-manipulation and structure, render difficult the attainment of proper combustion. With furnaces of ideal construction, and with adequate combustion temperatures, the problem would be solely one of air-admission and admixture. It would be necessary, however, to adapt the methods of furnace operation in accordance with the peculiarities of various fuels.

431. Anthracite is Usually Hand Fired.—It should be spread evenly, in small charges, at frequent intervals. Stirring or breaking up the fuel-bed with the slice-bar or poker should not be practiced. The thickness of the fires is, usually, not over 2 or 3 in. But the fuel-bed builds up between cleaning intervals. The total thickness may, therefore, be from 14 to 16 in. just before cleaning. The cleaning periods should be regulated in accordance with the combustion-rate and the quantity of the fuel. When cleaning fires, it should be remembered that anthracite is slow to ignite, and that a sufficient quantity of glowing fuel should, therefore, be retained. Combustion arches sprung over the grates assist in the ignition of freshly-fired fuel and in maintaining the furnace temperature high. (Mark's, MECHANICAL ENGINEERS' HANDBOOK.)

NOTE.—ARTIFICIAL DRAFT IS USUALLY EMPLOYED IN BURNING ANTHRACITE. For burning the smaller sizes, a blast equivalent to a 3-in. water column should be available. The stack should be so proportioned as to give a suction at all times within all parts of the boiler setting. A forced blast, with anthracite, causes rapid fouling of the heating surfaces. The dust carried over often amounts to 10 per cent. of the total quantity of coal fired. (Marks', MECHANICAL ENGINEER'SHANDBOOK.

432. To start a fire with soft (bituminous) coal the following method (Maujer and Bromley, FUEL ECONOMY IN BOILER

ROOMS) may be followed: The entire grate is covered (Fig. 337) with 3 in. of green coal spread evenly. Dry wood or shavings are then spread on top of the coal. On these, here and there over the surface, is put oil-soaked shavings or waste. The fuel is then ignited by throwing burning waste in the center of the grate. The blower is started lightly at first, or the damper and ash-pit doors are opened if no blower is used. The draft may be increased as necessary, coal should be thrown on, a little at a time, until the fire is going satis-

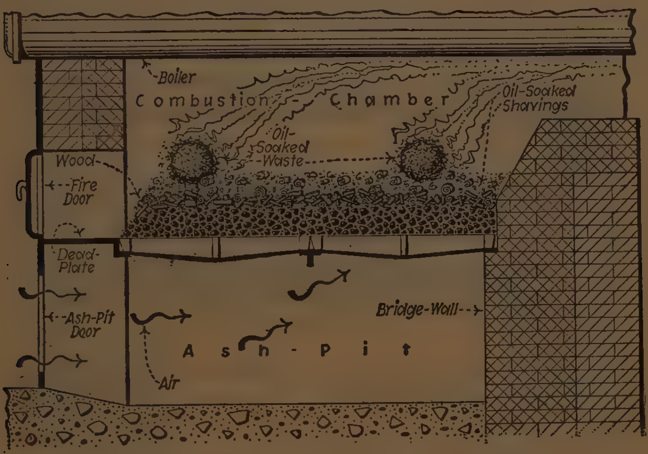


FIG. 337.—Starting a fire with soft coal in hand-fired furnace.

factorily. If a lumpy gas coal is available it should be first spread on the grate. The coal ordinarily used, and the shavings may then be laid. This will prevent the small coal falling through the grate. The fire burns from the top down. The volatile passes through the hot zone and becomes well vaporized, so that it mixes readily with the air supplied for combustion.

NOTE.—If the supply of kindling wood is comparatively scant, it may be conserved by starting the fire on the front end of the grate. The entire grate is first covered with coal, as described above. Bunches of shavings or oil-soaked waste are then placed just back of the dead plate in each door. The kindling wood, broken into about 15-in. lengths, is next laid cribwise on top of the waste. Coal is then shoveled in on

top of the wood until a mound of fuel, as high as can be conveniently obtained, is built up just inside each door. The bunches of shavings or waste are now ignited. The ash-pit doors are partially closed and the furnace doors are left ajar until the banked up masses of coal are burning throughout. The glowing fuel is then spread out and a thin layer of fresh fuel is added. An anthracite, coke, or soft coal fire can be started in this way.

433. Hand-firing of bituminous coal (Hand-firing Soft Coal Under Power-plant Boilers, Henry Kneisinger, *Government Printing office*) secures good results, generally, only when certain fundamental rules are scrupulously observed. These are:

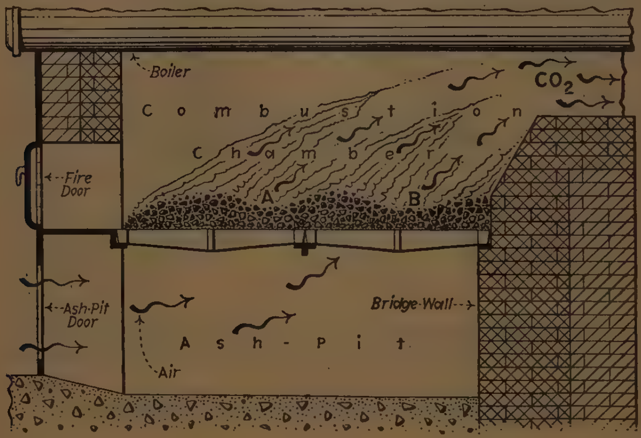


Fig. 338.—A well kept fuel bed before firing.

(1) *The fire should be kept level by depositing the green fuel only where the fire* (*A* and *B*, Fig. 338) *shows signs of thinning out.* Deep depressions in the fuel bed, (Fig. 339) should not be filled at one firing. An excessive depth of green coal might cake and retard combustion in the depression. At the same time, replenishment of the high places, *HH*, should be omitted for one or two firings.

(2) *A proper thickness of fuel-bed should be maintained.* This factor is contingent, mainly, upon the grade and quality of the coal and the strength of the draft. It may be from 4 to 10 in.

(3) *The coal should be fired in small quantities and at short intervals.* This tends to keep the fuel-bed level and prevents the formation of large volumes of dense black smoke.

(4) *The fuel-bed should not be leveled or otherwise disturbed with the slice- bar or poker.* If the fire is leveled with the slice-bar, the furnace doors must remain open during the operation. A large excess of air will thus be admitted to the furnace. Impaired efficiency will result. Stirring the fire-bed will inevitably lead to difficulty if the coal is of a clinkering variety. This will be due to fusing of the ash by mixture with the glowing fuel.

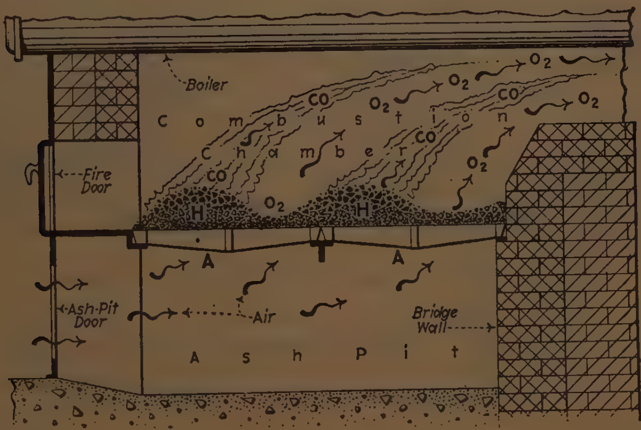


FIG. 339.—Condition after several firings when fuel is spread evenly over whole grate without noting thick and thin spots.

(5) *The ash-pit doors should be kept open at all times while the boiler is being operated.* The draft should be controlled with the damper, not with the ash-pit doors.

(6) *Excessive accumulations of furnace refuse in the ash-pit should be avoided.* Clogging of the ash-pit in this manner may result in an uneven distribution of the air-supply under the grate. A 2- or 3-in. depth of water in the ash-pit may be of benefit in preventing adherence of clinker to the grate.

NOTE.—PROPER THICKNESSES OF THE FUEL-BED for different coals (Mark's MECHANICAL ENGINEERS' HANDBOOK) are: (1) *For semi-bituminous coals, as Pocahontas, New River, Clearfield, from* 12 *to* 14 *in.* (2) *For*

bituminous coals from the Pittsburgh mining district, Ohio, Illinois, Kentucky and Tennessee, from 4 to 6 in. (3) *For free-burning coal from the Rock Springs, Wyoming, mining district, from 6 to 8 in.* (4) *For low-grade coals from Montana, Utah and Washington, about 4 in.*

The Quantity of Coal to be Used in Each Firing (Henry Kreisinger Firing Soft Coal Under Power-Plant Boilers, *Government Printing Office*) depends upon the size of the grate and the intensity of the draft. When the total available draft in the uptake is about 1 in. of water, 2 to 2.5 lb. of coal fired per sq. ft. of grate area is a fair average. Thus, on a grate 8 ft. wide and 6 ft. deep, each firing would average 100 to 125 lb. of coal, or about 6 to 9 shovelfuls.

The Intervals Between the Firings should be, on the average, about 5 min. long. If the draft is quite high, the periods may be short-

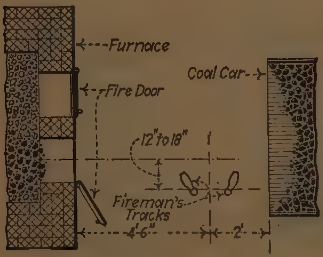


Fig. 340.—Correct fireman's position for good firing.

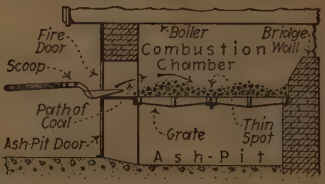


Fig. 341.—The end of throw in scooping coal into furnace.

ened to 3 min. With a weak draft and sluggish fires, the interval may sometimes be lengthened to 8 min. Under ordinary circumstances it should never be longer than 10 min. Small and frequent firings make the coal-supply more nearly proportional, than otherwise, to the air-supply. The latter, with most hand-fired furnaces, is nearly constant. Small and frequent firings also tend to prevent the formation of a crust on the fire-bed and the formation of holes therein.

The Firing-position Adopted by the Fireman largely influences his ability to place the coal exactly where needed. For firing through the left-hand door of a furnace he should assume a position (Fig 340) as indicated by the foot prints. A corresponding position should be taken when firing through the right-hand door. The scoopful of coal should be swung with sufficient velocity to cause the coal to be propelled by its own momentum to the proper place in the furnace, when the bottom of the scoop (Fig. 341) strikes the dead-plate. Dexterity in this operation identifies the proficient fireman.

434. Spreading the Coal Uniformly over the Entire Fire-bed Area should be Avoided.—Such practice may produce thick spots, *H*, (Fig. 339) and the corresponding thin spots.

NOTE.—If fresh coal were were thrown on heaps, *HH*, (Fig. 339) it might not get sufficient air to support proper combustion. Thus the volatiles might pass from the furnace imperfectly burned. This would be manifested by smoke. But air would pass freely through the thin spots *AA*. Consequently, the fresh fuel which might cover these spots, and that which might lie at the edges of the heaps, would burn with a bright flame. Being obscured from the fireman's view, the thin spots might continue unobserved and unreplenished. The fuel on them might burn through to the grate. Thus a great excess of air would have access to the furnace. Then, when the fireman would throw some coal on the thin spots, a part of the coal would slip through the bars to the ash-pit and thus be wasted.

THIN SPOTS MAY BE BURNED IN THE FUEL-BED if the firing periods are too far apart. They may also be due to the more rapid combustion that will occur over limited areas of the grate through which the air may flow more freely than through the surrounding areas. Such freedom of air-flow might be due to less compact masses of furnace refuse on the particular areas of the grate where the greater rapidity of combustion occurs. It might also be due to a less compact condition of the mass of fuel in those particular locations.

THE APPEARANCE OF THE FLAME MAY REVEAL THE PRESENCE OF THICK OR THIN SPOTS IN A FUEL-BED. Patches of bright, hot, flame usually indicate thin spots. Patches of sluggish, smoky, flame, or no flame at all, usually indicate thick spots. Removal of clinker at the bottom of thick places is, generally, a necessary remedial measure.

435. Two general methods of hand-firing are commonly practiced: (1) *The alternate or spreading method.* (2) *The coking method.*

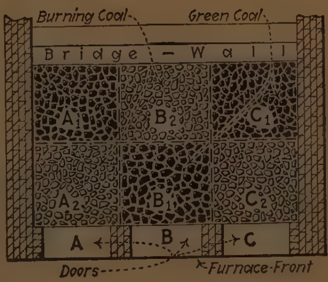


FIG. 342.—A method of alternate firing.

NOTE.—HAND-FIRING BY THE ALTERNATE METHOD consists in spreading a charge of green coal over one certain portion of the grate area at one firing, and over another certain portion at the next firing. The idea is to continually preserve an area of incandescent fuel over which the volatiles distilled from the freshly-fired fuel may pass. A 3-door furnace (Fig. 342) may be alternately fired (BUREAU OF MINES BULLETIN) thus: The portions A_1 and C_1 of the rear half of the grate area, which are respectively opposite doors *A* and *C* are, at one firing, charged through these doors. The portion of the front half *B*1 which is opposite door *B* is charged through door *B*. At the next firing, the end portions, A_2 and C_2,

of the front half of the grate are respectively replenished through doors *A* and *C*, while the middle portion B_2 of the rear half is replenished through door *B*. The firing may often be done along alternate narrow strips extending from the furnace-front to the bridge-wall.

HAND-FIRING BY THE COKING METHOD consists in banking the charge of green fuel (Fig. 343) to a considerable depth on the front end of the grate. There, it remains until a large portion of the gases is burned out. The mass of partially-coked fuel thus formed is then pushed back and spread over the grate. A bed of incandescent fuel is thus constantly maintained on the rear half of the grate. The gases from each succeeding charge of green fuel are ignited and burned while passing over

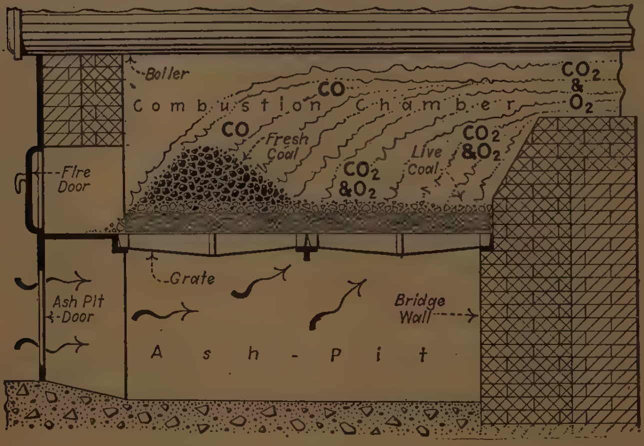


FIG. 343.—The coking method of firing.

this bed. It may be necessary to hold the fire-doors slightly ajar in order to admit sufficient air for the combustion of the profuse volume of gases streaming from the banked-up mass of fuel.

436. The relative advantages and disadvantages of the alternate and of the coking firing-methods may be enumerated (FINDING AND STOPPING WASTES IN MODERN BOILER ROOMS, *Harrison Safety Boiler Works*) as follows:

With the alternate method: (1) *Higher efficiency of combustion may result.* (2) *The percentage of* CO_2 *may be greater.* (3) *The temperature of the flue gases may be lower.* (4) *Steam-generation may be more uniform.* (5) *More clinker and ash may accumulate in the furnace.*

With the coking method: (1) *The time-intervals between successive firings are longer.* (2) *Smoke may be abated.* (3) *Fluctuating loads are handled with greater difficulty.* (4) *Unseen holes may develop in the fuel-bed.* (5) *The percentage of CO_2 may be smaller.* This may be due to the greater requirement for excess air.

437. Economy in the hand-firing of lignite is, generally, secured with greater difficulty than is economy in the hand-firing of bituminous coal. The comparatively larger volatile content of lignite mainly accounts for this. Proper results, with lignite, depend largely upon the type of furnace (Fig. 356) which is used.

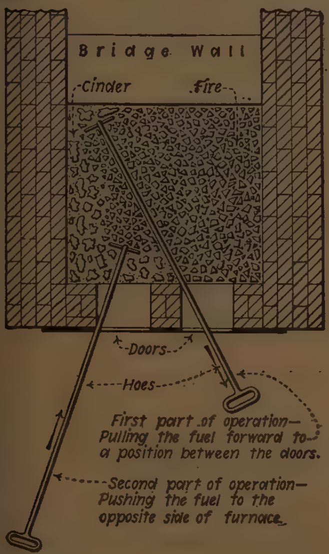


FIG. 344.—Side method of cleaning with hoe.

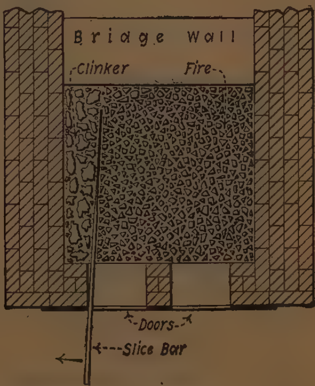


FIG. 345.—Side method of cleaning with slice bar.

NOTE.—The thickness of a furnace-bed of lignite should, generally, be from 4 to 6 in. The spreading method of firing should be used. Steam-jets in the ash-pit may be utilized to advantage for preventing fusion of the clinker with the grate. Smoke prevention with a lignite fire is difficult.

438. Two general methods of cleaning a hand-fired furnace are available: (1) *The side method* (Figs. 344 and 345). (2) *The front-to-rear method* (Fig. 346).

NOTE.—IN THE SIDE METHOD OF FURNACE-CLEANING (Figs. 344 and 345) one-half of the grate-area, from the furnace-front to the bridge-

wall, is cleaned at a time. The hoe may be used (Fig. 344) to scrape the coked fuel, from the side which is to be cleaned first, over to the opposite side.

A more-convenient and practical method is to use the slice-bar (Fig. 345) for "winging" the fuel, from the side which is to be cleaned, over to the opposite side. The bared mass of furnace refuse is next broken up with the slice-bar. It is then hoed out onto the floor. The burning fuel is now winged over onto the bare half of the grate. Then enough green fuel to form a substantial bed is shoveled in on top of it. When the fire begins to burn intensely on the clean half of the grate, the remaining half is cleaned likewise.

In The Front-to-rear Method of Furnace-cleaning (Fig. 346) the coked fuel on one-half of the grate is pushed, with the hoe, back to the bridge-wall. The mass of refuse thus exposed is then hoed out. The

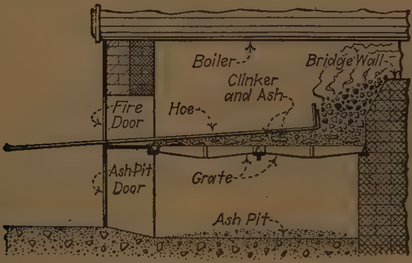


Fig. 346.—Front-to-rear method of cleaning fire.

burning fuel is next pulled forward and leveled on the bare grate. The clean half of the fire is now replenished. When the fresh fuel is burning properly, the remaining half of the grate is similarly cleaned.

Thorough cleaning of a furnace is practically impossible with the front-to-rear method. This method is a makeshift which should be resorted to only under stress of an emergency, as when abnormal or unusual conditions of service might not allow the time necessary for proper cleaning by the side method.

QUESTIONS ON DIVISION 15

1. What is meant by combustible? Combustion?
2. Why is air necessary for combustion?
3. How is it possible to determine the completeness of combustion?
4. How much air is actually required for combustion of coal? How much is actually used in practice?
5. What general requirements must be met for proper combustion?
6. What makes proper combustion difficult?
7. How is anthracite fired?
8. Discuss a method of starting a soft-coal fire.
9. Give the general directions for firing soft coal.
10. Does the fuel-bed thickness vary for different coals? How much?

11. Discuss the two general methods of firing soft coal.
12. Compare with reference to results, obtained the two general methods of firing.
13. How may thin spots in the fuel bed be eliminated?
14. What is the result of long firing periods?
15. What happens if the fireman persists in spreading the coal evenly over the fuel ed?
16. How may the fuel bed be quickly leveled? Is this method advisable?
17. How often should soft coal be fired? Discuss.
18. Describe the proper standing position for the fireman.
19. Describe two methods of cleaning fires.
20. Compare the effectiveness of the two general methods of cleaning a fire.

DIVISION 16

BOILER SETTINGS AND FURNACES

439. The setting of a stationary steam boiler consists, generally, of a masonry structure upon which the boiler may rest (Fig. 347), or within which it may be independently supported (Fig. 348), by a steel frame-work. The setting encloses a furnace, *F* (Fig. 349), a combustion chamber *C*, an

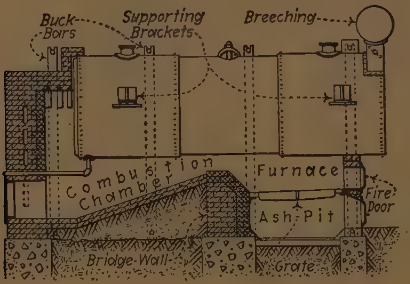


Fig. 347.—The original Hartford setting for return tubular boiler.

ash-pit *A*, and variously arranged passages *P* through which the products of combustion may travel to the chimney uptake.

Note.—The Materials Of Boiler Settings may consist of ordinary kiln-burned brick, fire-brick in various shapes (Fig. 350), clay tile, concrete, fire-clay, lime mortar, cement, and steel plate.

A Complete Boiler-Setting may be regarded as including the furnace, grate (Fig. 349), or stoker (Fig. 351), the doors and frames of its various external openings (Fig. 351), the buck stays or buckbars (Fig. 347), and other strengthening and staying devices. Dampers, steam-jet blowers and other intimately connected draft-controlling and draft-producing devices may be regarded as its accessories.

440. Table Of Specifications For Chicago Setting Of Horizontal Return Tubular Boilers (Figs. 348 and 349).[1]

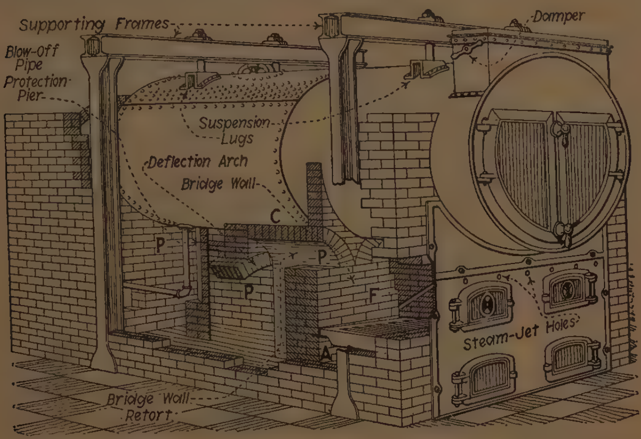


FIG. 348.—Chicago setting for a horizontal return tubular boiler.

NOTE.—First-grade firebrick should be used for the bridge-wall, deflection arch and *V*-pier, and for the furnace and combustion-chamber lining

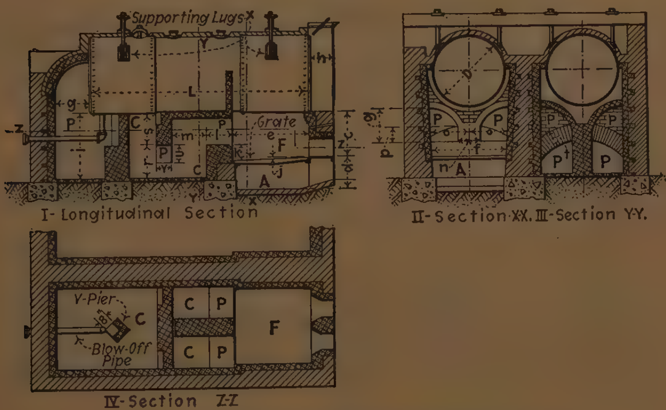


FIG. 349.—Details of Chicago boiler setting.

back to a vertical plane 1 ft. from the rearward face of the deflection arch. Second-grade firebrick may be used for lining the rearward portions of

1 Adapted from Maujer and Bromley's FUEL ECONOMY IN BOILER ROOMS (Second edition). See page 255 for table.

the combustion-chamber. Common brick may be used for the combustion-chamber floor. For boilers which are to carry a working pressure of 20 lb. or under, the fire-doors must, when closed, admit air through register-

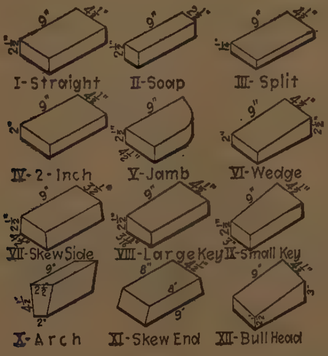


FIG. 350.—Fire-bricks of various shapes.

ed openings having an area of 4 sq. in. per sq. ft. of grate area. If desired, such doors may be used for boilers which carry greater pressure than 20 lb. The effective area of the damper frame must not be less

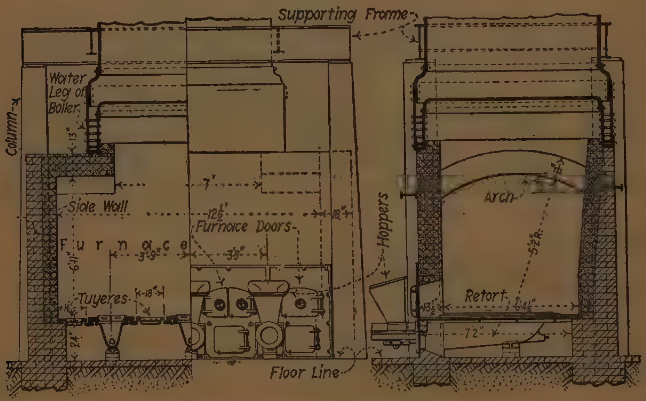


FIG. 351.—Setting for Jones underfeed stokers under Manning vertical fire-tube boiler.

than the total cross-sectional area of the tubes. Breechings are to be erected in conformity with local ordinances. The table is applicable for ordinary requirements.

440A. "Chicago" Return-Tubular-Boiler Setting Specifications (See p. 253).

Diameter shell	84″	84″	78″	78″	72″	72″	66″	66″	60″	60″	54″	54″
Length shell	20′	18′	20′	18′	18′	16′	18′	16′	18′	16′	16′	14′
c	42″	42″	42″	42″	36″	36″	36″	36″	36″	36″	36″	36″
d	2′ 2″	2′ 2″	2′ 2″	2′ 2″	2′	2′	2′	2′	1′ 10″	1′ 10″	1′ 10″	1′ 10″
e	6′ 6″	6′	6′ 6″	6′	6′	5′ 6″	5′ 6″	5′	5′ 6″	5′	4′ 6″	4′
f	7′	7′	6′ 6″	6′ 6″	6′	6′	5′ 6″	5′ 6″	5′	5′	4′ 6″	4′ 6″
g	2′ 10″	2′ 10″	2′ 8″	2′ 8″	2′ 6″	2′ 6″	2′ 4″	2′ 4″	2′ 2″	2′ 2″	2′	2′
h	1′ 10″	1′ 10″	1′ 9″	1′ 9″	1′ 8″	1′ 8″	1′ 7″	1′ 7″	1′ 6″	1′ 6″	1′ 5″	1′ 5″
i	6′ 4″	5′ 10½″	6′ 5½″	6′	5′ 11½″	5′ 6½″	5′ 7″	5′ 1½″	5′ 9″	5′ 4″	4′ 11″	4′ 8″
j	6½″	6″	6½″	6″	6″	5½″	5½″	5″	5½″	5″	4½″	4″
k	1′ 10½″	2′	1′ 9½″	1′ 11″	1′ 6″	1′ 7″	1′ 7″	1′ 8″	1′ 5½″	1′ 6½″	1′ 7½″	1′ 6″
l	2′ 3″	2′ 3″	2′ 3″	2′ 3″	2′	2′	1′ 10½″	1′ 10½″	1′ 10½″	1′ 10½″	1′ 6″	1′ 6″
m	3′	3′	2′ 10″	2′ 10″	2′ 6″	2′ 6″	2′ 4″	2′ 4″	2′ 2″	2′ 2″	2′	2′
n	1′ 6″	1′ 6″	1′ 6″	1′ 6″	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″
o	2′ 9″	2′ 9″	2′ 6″	2′ 6″	2′ 5½″	2′ 5½″	2′ 2½″	2′ 2½″	1′ 11½″	1′ 11½″	1′ 8½″	1′ 8½″
p	1′ 4″	1′ 2″	1′ 5½″	1′ 3½″	1′ 1″	1′ 1½″	1′ 1½″	1″	1′ 3″	1′ 1½″	1′ 1½″	1′ 2½″
q	2′ 5½″	2′ 3½″	2′ 5½″	2′ 3½″	2′ 2″	2′ ½″	2′ ½″	1′ 11″	2′ ½″	1′ 11″	1′ 8½″	1′ 9″
r	4′ 2″	3′ 10½″	4′ 2½″	3′ 11″	3′ 11½″	3′ 8″	3′ 8½″	3′ 4½″	3′ 9″	3′ 5½″	3′ 2″	2′ 10″
s	2′ 2″	2′	2′ 3″	2′ 1″	2′	1′ 10½″	1′ 10½″	1′ 9″	2′	1′ 10½″	1′ 9″	1′ 10″
t	9″	9″	9″	9″	9″	9″	9″	9″	9″	9″	9″	9″
u	1′	1′	1′	1′	1′	1′	11″	11″	10″	10″	9″	9″
v	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″	1′ 1½″
Number of tubes and size of tubes	92–4″	92–4″	88–4″	88–4″	70–4″	70–4″	54–4″	54–4″	46–4″	46–4″	36–4″	36–4″
Heating surface in tubes, sq. ft.	1932.0	1738.8	1842.8	1658.5	1323.0	1176.0	1017.7	904.6	866.9	770.6	604.8	529.2
Heating surface in shell, sq. ft.	219.9	197.9	204.2	183.8	169.6	150.7	155.5	138.2	141.3	125.6	113.1	99.0
Total heating surface tubes and shell, sq. ft.	2151.9	1936.7	2047.0	1842.8	1492.6	1326.7	1173.2	1042.9	1008.2	896.2	717.9	628.2
Boiler horsepower	215.0	194.0	205.0	184.0	149.0	133.0	117.0	104.0	101.0	90.0	72.0	63.0
Square feet of grate surface	45.5	42.0	42.25	39.0	36.0	33.0	30.25	27.5	27.5	25.0	20.25	18.0
Cross-sectional area of each bridge wall retort, sq. in.	820.0	756.0	761.0	702.0	648.0	594.0	544.5	495.0	495.0	450.0	364.5	324.0
Horizontal area between bridge wall and deflection arch, sq. in.	2448.0	2448.0	2040.0	2040.0	1770.0	1770.0	1484.0	1484.0	1326.0	1326.0	984.0	984.0
Vertical area under deflection arch	3280.0	3024.0	3041.0	2808.0	2592.0	2376.0	2177.0	1979.0	1979.0	1800.0	1457.0	1296.0
Total cross-sectional area of tubes, sq. in.	1011.0	1011.0	967.0	967.0	769.0	769.0	593.0	593.0	505.0	505.0	396.0	396.0
Total cross-sectional tube area + 25 per cent.	1264.0	1264.0	1208.0	1208.0	961.0	961.0	741.0	741.0	631.0	631.0	495.0	495.0

441. The furnace of a masonry-set stationary steam boiler includes all of the enclosed space wherein the fuel is burned. Its essential adjuncts Fig. 347 are a grate, a bridge wall and a fire-door.

442. The combustion chamber of a masonry-set stationary steam boiler includes all of the enclosed space wherein may be completed the combustion of the gases which were distilled from the fuel in the furnace. It may contain an arrangement of arches (Figs. 348 and 349) or baffles for obtaining a thorough commingling of the supply of oxygen with the distilled gases.

443. The requisites of a boiler setting, with its adjuncts and accessories, are principally as follows: (1) *Capacity for developing a rate of combustion, if so required, by which the nominal horsepower rating of the boiler may be exceeded by at least* 200 *per cent.* (2) *Enclosure of a sufficient volume of space to give the distilled gases unrestricted opportunity for thoroughly mixing with the air which is admitted for combustion.* (3) *Provision, if the quality of the fuel so requires, of wing-walls, arches,* (Figs. 348 and 349) *baffles, or restricted passages to facilitate mixture of the combustible gases with the air.* (4) *Provision, if practicable, of a refractory surface upon which the distillates from the freshly-fired fuel may directly impinge.* (5) *Exclusion of air from the enclosed space except by entrance through channels regularly provided therefor.* (6) *Ability to resist disintegration and distortion by high temperatures and abrupt changes of temperature.*

NOTE.—Boiler settings of radically incorrect design, and settings which are ill-adapted for the particular quality of fuel which is used, are prevalent sources of waste. Approximately one-half of the process of complete combustion, of the coal which is supplied to a boiler furnace, occurs within the fuel-bed. The remaining one-half should be performed in the furnace space above the fuel-bed and in the combustion chamber. With many settings the gases arising from the fuel-bed require only a fraction of a second to pass thence to the region adjacent to the uptake, where the temperature is too low to support combustion.

If complete combustion is to be consummated within this brief interval, the globules of liquid hydrocarbons, which ascend from the fuel-bed with the gases, must themselves vaporize into gas. The whole volume of the combined gases and soot must then commingle with the air supply and unite with the oxygen therein. The combination of oxygen with

such combustible gases is relatively slow. Hence the importance of providing ample combustion-space and long gas passages is evident.

444. The Chicago setting for return tubular boilers (Figs. 348 and 349) satisfies the conditions for smokeless and economical combustion of Central Western coals more effectively than do settings of the older types (Fig. 347). The furnace gases pass in a divided stream over the bridge wall. In their progress through the retorts *P* and *P* they are thoroughly mixed and heated. Passage under the deflection arch promotes farther mixing of the gases.

NOTE.—The old standard Hartford setting (Fig. 347) is no longer used or approved by its original designers.

445. The necessary volume of combustion space in a boiler setting depends upon the nature of the fuel which is to be used. It has been demonstrated experimentally that, for the same rate of combustion and quantity of excess air (Sec. 428), a highly volatile coal (Secs. 416, 417, 418) requires a larger combustion space than does one which is less volatile.

EXAMPLE.—For equal rates of combustion and quantities of excess air, Pittsburgh coal, which has a volatile content of 35 per cent., requires about 20 per cent. larger combustion space than does Pocahontas coal, which has a volatile content of 18 per cent. Also, Illinois coals which has a volatile content of 46.5 per cent., requires about 40 per cent. more combustion space than does Pocahontas coal.

NOTE.—The requisite volumes of combustion space in boiler settings do not vary in direct proportion to the volatile contents of the coals which are to be burned. The exact relation has not been determined. It has, however, been ascertained that when the combustion-rate of a given coal is doubled, thus doubling the rate of distillation of its volatile constituents, the combustion space need be increased only 20 per cent., in order that the original efficiency of combustion, with the same quantity of excess air, be maintained.

NOTE.—The accompanying illustrations from Maujer and Bromley's FUEL ECONOMY IN BOILER ROOMS (Figs. 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361 and 362) show boiler settings which are well adapted for coals with volatile contents of from 12 to 40 per cent. For lignites, with from 25 to 40 per cent. moisture, or for slack coal, with from 15 to 20 per cent. moisture, a furnace (Figs. 361 and 362) which directs the flames forward over the green fuel, thus evaporating much of the moisture as the fuel is fed into the furnace, is particularly well suited.

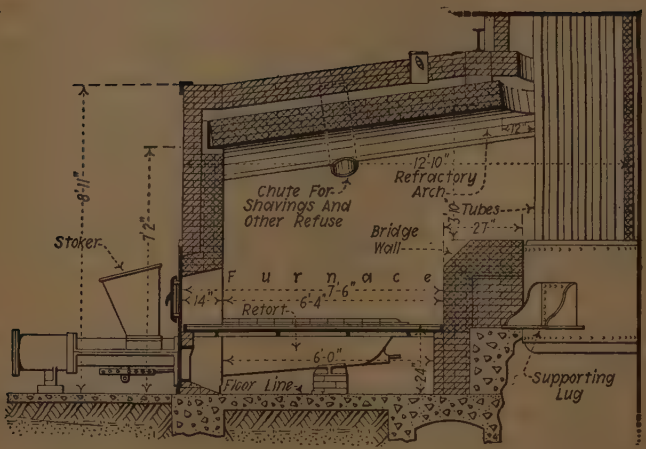


FIG. 352.—Dutch-oven furnace setting for vertical straight water-tube boiler equipped with Jones underfeed stoker.

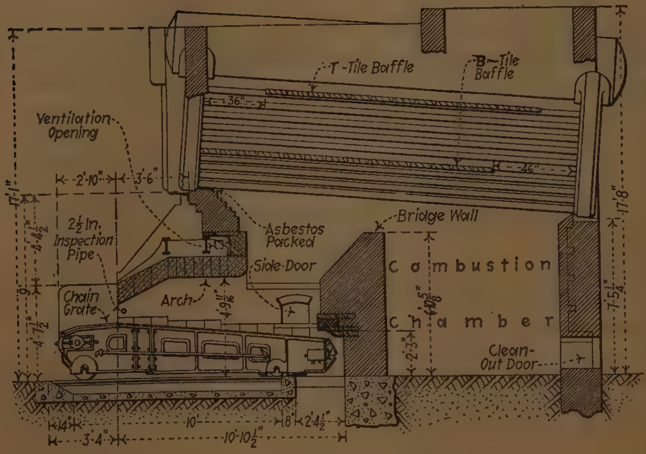


FIG. 353.—Setting for a horizontally inclined water-tube boiler equipped with chain-grate stoker and baffles lengthwise.

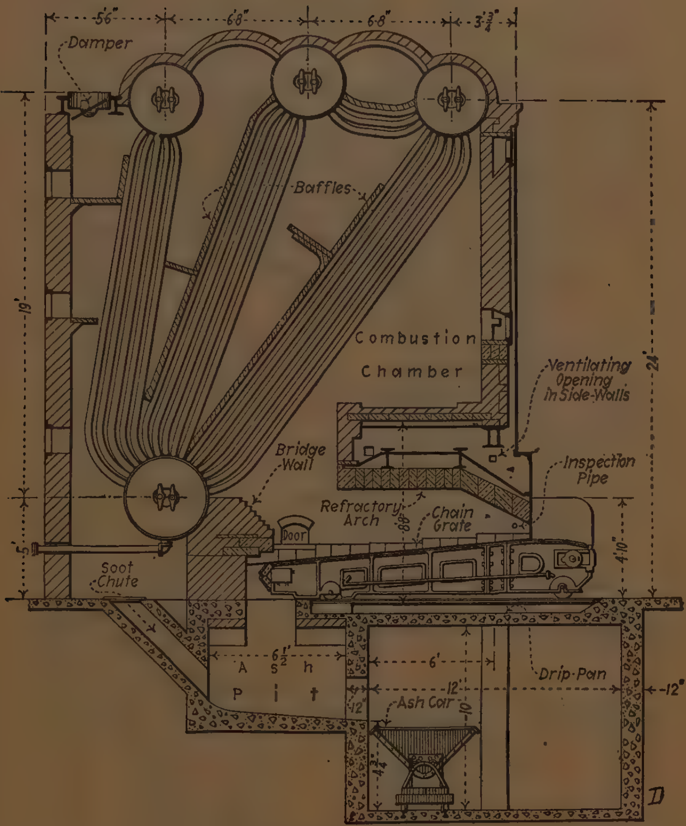


FIG. 354.—Setting for a vertically inclined water-tube boiler equipped with chain-grate stoker.

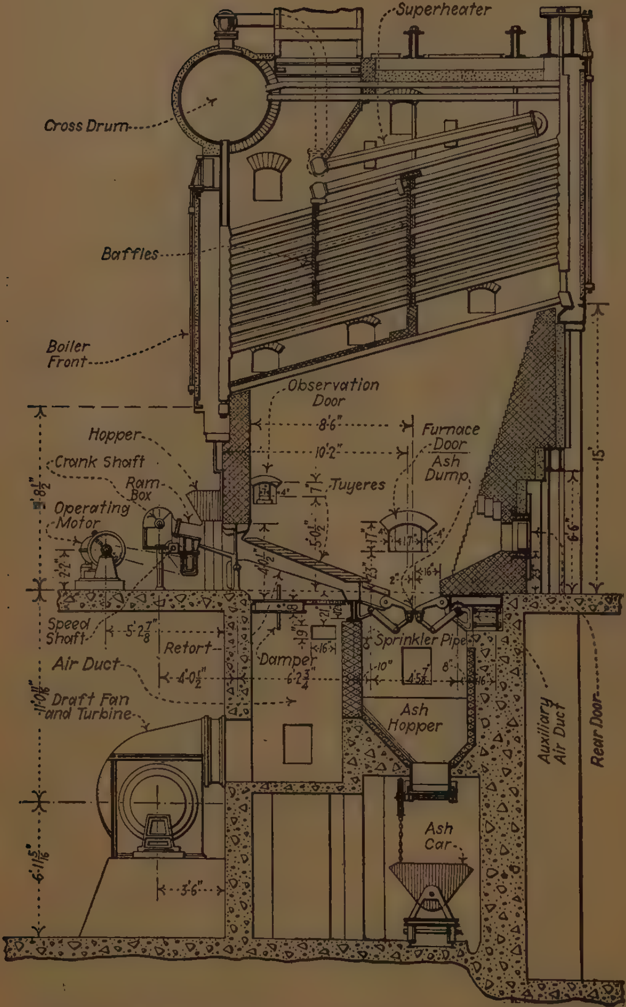


FIG. 355.—Setting for cross-drum horizontally-inclined water-tube boiler equipped with Westinghouse-type underfeed stoker and cross-wise baffles.

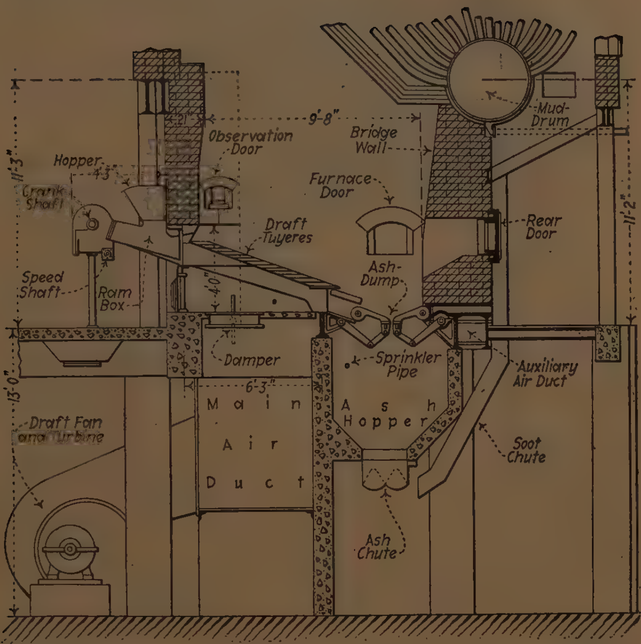


FIG. 356.—Setting for vertically-inclined water-tube boiler equipped with Westinghouse-type underfeed stoker for burning lignite.

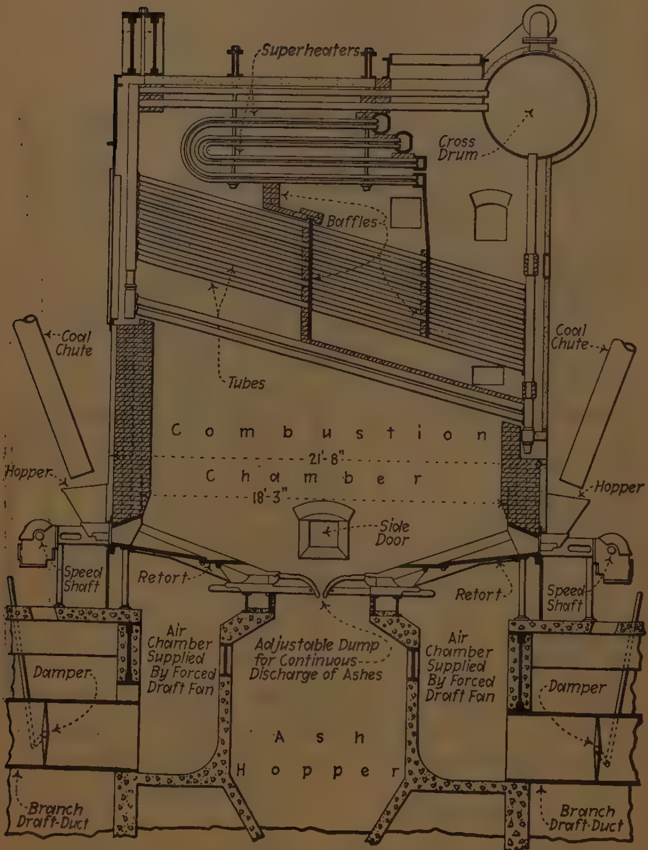


FIG. 357.—Setting for cross-drum horizontally-inclined water-tube boiler equipped with underfeed stokers, front and rear, and cross-wise baffles.

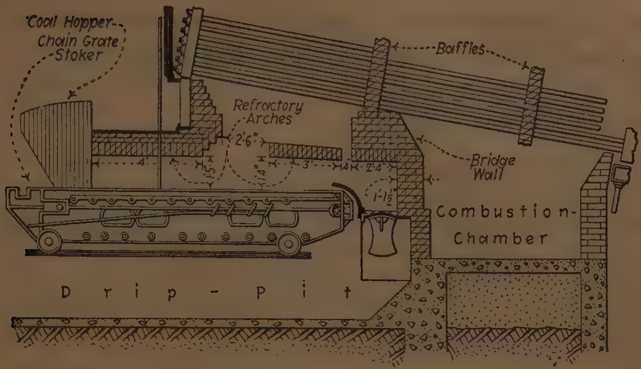


FIG. 358.—Setting for horizontally-inclined cross-baffled water-tube boiler equipped with chain-grate stoker for burning slack-coal high in moisture (designed by J. F. McCall).

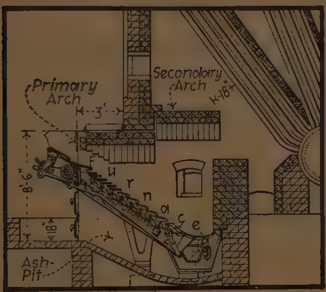


FIG. 359.—Furnace setting with secondary arch for vertically-inclined water-tube boiler equipped with front overfeed step-grate stoker.

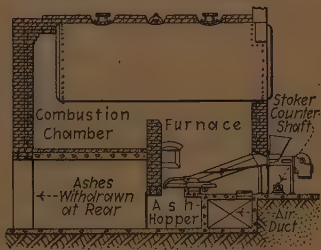


FIG. 360.—Setting of horizontal return tubular boiler equipped with underfeed stoker.

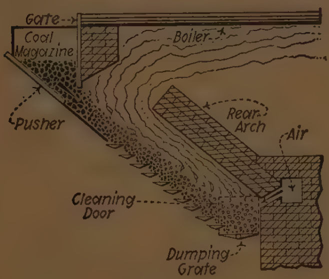


FIG. 361.—Furnace setting for burning lignite with front overfeed step-grate stoker.

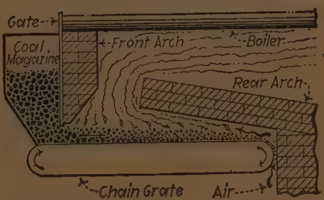


FIG. 362.—Furnace setting for burning lignite with chain-grate stoker.

446. An ample ratio of combustion-space volume to grate area (Table 447) is very necessary to economy in the use of boiler fuel. Ratios of 10 cu. ft. to 1 sq. ft. are common in modern boiler installations.

NOTE.—The transverse and lengthwise dimensions of a boiler setting, relative to the boiler dimensions, are in most cases comparatively fixed quantities. But the height usually affords a factor of sufficient flexibility to permit of a correct proportionment of the volume of enclosed space. As a general proposition, a boiler setting should be made as high (Table 448) as practical considerations will permit. This may be done regardless of any definite rate of combustion.

447. Table.—Ratios of Combustion-Space Volumes to Grate Areas, which Correspond to Different Percentages of Efficiency in the Combustion of Three Grades of Coal Containing Different Percentages of Volatile Matter.

Per cent. of complete combustion	Combustion rate in lb. per sq. ft. of grate area per hr.	Per cent. of excess air over quantity theoretically required for complete combustion	Requisite ratio of combustion—space volume in cu. ft. to grate area in sq. ft.		
			Pocahontas, 18.5 per cent. volatile matter	Pittsburgh 35 per cent. volatile matter	Illinois 46.5 per cent. volatile matter
95.0	50	50	2.7	2.9	4.3
97.0	50	50	3.2	3.7	5.3
98.0	50	50	3.6	4.4	6.3
99.0	50	50	4.0	5.6	8.9
99.5	50	50	4.8	6.8	11.9
95.0	25	50	2.0	2.2	3.5
97.0	25	50	2.3	2.7	4.35
98.0	25	50	2.7	3.1	5.1
99.0	25	50	3.4	4.0	6.2
99.5	25	50	4.0	5.0	7.1

Adapted from Bureau of Mines Bulletin No. 135.

448. Table.[1]**—Suggested Heights For Settings of Horizontal Return Tubular and Horizontally-Inclined Water-tube Boilers.**

Type of furnace or stoker	Horizontal return tubular boiler		Horizontally inclined water tube boiler	
	Distance, in inches, from shell to deadplate	Distance, in inches, from shell to floor	Distance, in inches, from bottom of headers of water-leg to floor, with lengthwise baffles	Distance, in inches, from bottom of header or water-leg to floor, with crosswise baffles
Chicago (Figs. 348, 349) . . .	Table 440A	Table 440A		
Hand stokers (Fig. 363) . .	36		72	72
Chain grate (Fig. 364)	48 to 54		72 to 96	78 to 96
Side feed stoker (Fig. 365).		90	90 to 120	120 to 144
Front feed stoker (Figs. 366		84	96	120
367		96	96	120 to 144
Underfeed stoker, Jones type (Fig. 370, 371)		66	72	72 to 84
Under feed stoker, Westinghouse type (Fig. 368) . .		72	84	120 to 168
Fuel oil (Figs. 377, 378) . .		72	84	96 to 120

QUESTIONS ON DIVISION 16

1. What mutual structural relation may exist between a stationary steam boiler and its setting?

2. Into what main divisions or compartments may the space enclosed by a boiler setting be regarded as separated?

3. Of what materials are boiler settings ordinarily made?

4. What items of construction and equipment, aside from the masonry, may be regarded as included in a complete boiler setting? What may be regarded as accessory appliances?

5. What details constitute the essentials of a simple boiler furnace?

6. What is the function of a boiler furnace?

7. What space does the combustion chamber of a boiler setting comprise?

8. What is the office of a combustion chamber?

9. What are the six essential requisites of a complete boiler setting?

10. Why is a large combustion chamber desirable in a boiler setting? What advantage accrues from long gas passages?

11. What is the principal factor by which the requisite volume of combustion space in a boiler setting is gauged?

12. What approximate mathematical relation exists between the rate of combustion on the grate and the space necessary for thorough combustion?

13. What furnace arrangement conduces to effective combustion of fuels which have high moisture contents?

14. Through which dimensional factor in the design of boiler settings is flexibility in proportioning the combustion space secured?

[1]Adapted from Maujer & Bromley's Fuel Economy in Boiler Rooms (Second Edition).

DIVISION 17

MECHANICAL STOKERS

449. The principal functions of mechanical stokers (Figs. 363 to 372, inclusive) are: (1) *To promote economical combustion by supplying the fuel uniformly to boiler furnaces.* (2) *To conserve labor.* (3) *To provide a means for effective combustion of low grades of coal which might otherwise be unavailable as fuel.* (4) *To facilitate smokeless combustion.*

NOTE.—By feeding the fuel continuously to a boiler furnace, instead of intermittently, as with hand-firing, the supply of air may, at all times, be accurately regulated in conformity with the desired rate of combustion. This conduces to economy of fuel. In large plants, with fuel-consumptions of 200 tons or more per week, the labor-costs, with mechanical stoking, might be from 30 to 49 per cent. less than the labor-costs with hand-firing. In plants showing smaller weekly fuel-consumptions than 200 tons, the saving in labor-cost, with mechanical stoking, might show a corresponding diminishment. In a plant using but 10 or 12 tons of coal per week, the saving in this item might be nil. Low grades of coal cannot, usually, be profitably burned in hand-fired furnaces. Mechanical stoking secures a more profuse distillation of the combustible gases from such coals than does hand-firing. A distinct aid to economical combustion of low grade fuels is the self-cleaning feature of mechanical stokers. Mechanical stoking will not of itself, produce smokeless combustion. Much depends on the manner in which the stoker is handled. However, if a stoker of adequate capacity is properly installed and operated, smokeless combustion will, generally, be practically assured.

450. Whether or not to install a mechanical stoker, either hand-operated (Fig. 363) or motor- or engine-operated (Figs. 364 to 372 inclusive), is often a difficult problem to determine. In a plant of larger capacity than about 1000 boiler h.p., mechanical stoking may be a practical necessity, regardless of any peculiarities of situation or environment. In smaller plants, local circumstances may be the deciding factors.

NOTE.—It is claimed that mechanical stoking has proved profitable in plants of less than 100 boiler h.p. Compliance with local ordinances affecting the smoke nuisance often compels recourse to mechanical

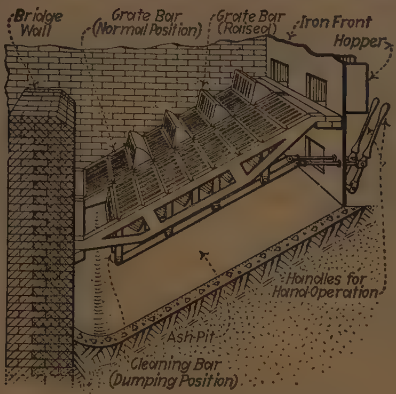


FIG. 363.—A Vasil hand stoker.

stoking. Generally, a mechanical stoker is not profitable unless the fuel can be fed to it by gravity from an overhead bin or bunker or by other mechanical means. Against a system of mechanical stoking must be

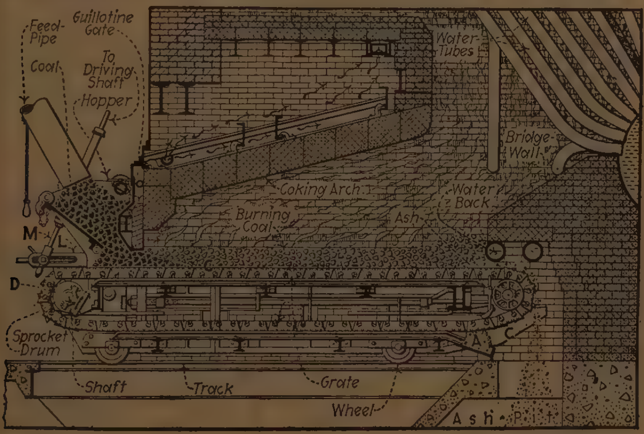


FIG. 364.—Green chain-grate mechanical stoker. (The pile denoted by the letter *A* is of ashes which constitute an air seal.)

charged the interest on the investment, the depreciation, the cost of repairs, power for operation, and power for supplying artificial draft, if such is necessary. If the saving in fuel and labor costs, the elimination

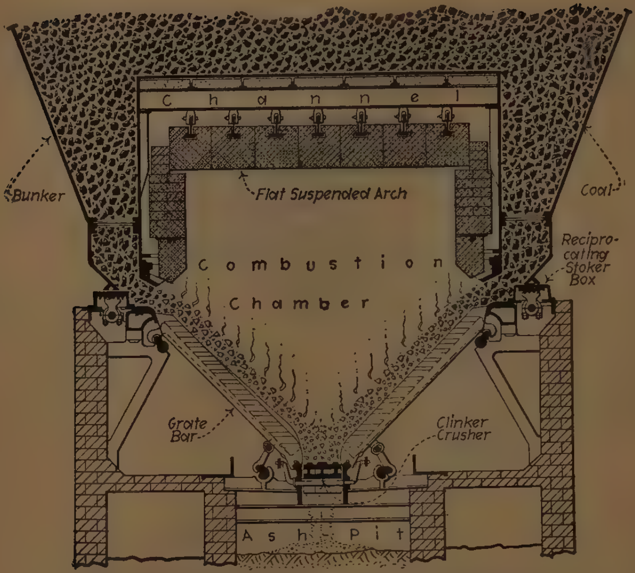


FIG. 365.—Detroit side overfeed mechanical stoker.

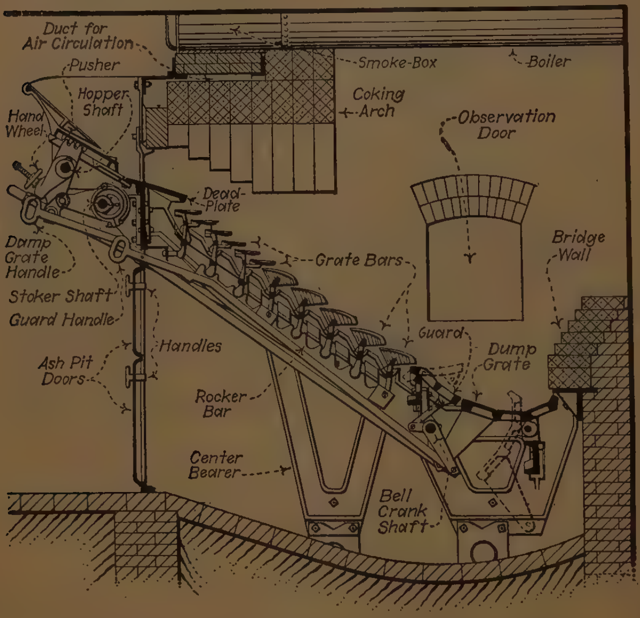


FIG. 366.—Roney front overfeed (step-grate) stoker.

of smoke, and the convenience which accrues, may be regarded as adequately offsetting the cost items enumerated, then installation of a suitable system of mechanical stoking is advisable.

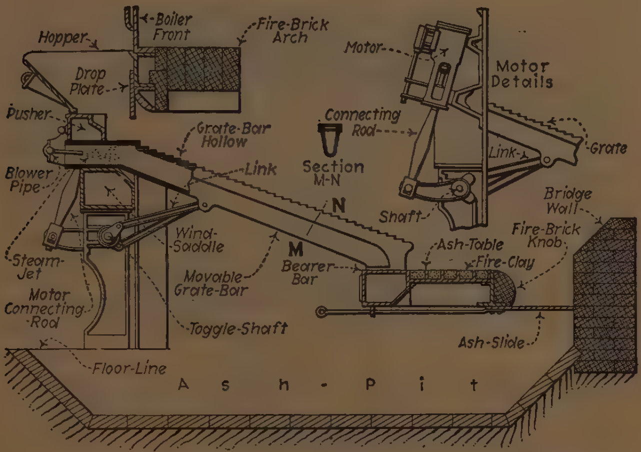


FIG. 367.—Wilkinson front overfeed (step-grate) stoker.

451. The operating principles of mechanical stokers are various. In general, the coal is fed automatically into the

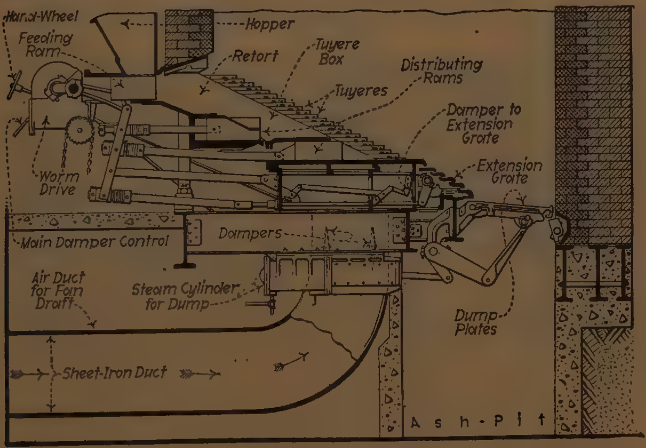


FIG. 368.—Taylor underfeed stoker.

furnace in a continuous stream. Also, automatic cleaning of the fire is effected continuously.

NOTE.—The grate of an automatic stoker may be (Fig. 364) in the form of an endless belt which conveys the fuel into the furnace. Or, the grate may be (Figs. 365, 366 and 367) in the form of a series of oscillating

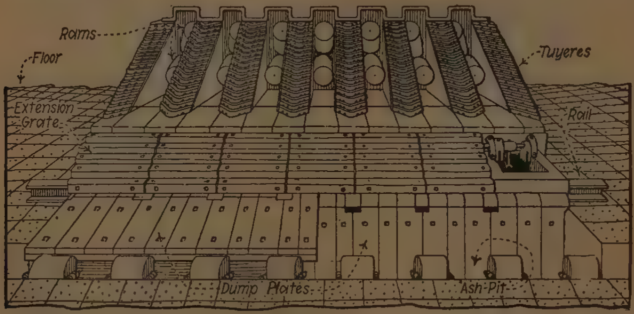


FIG. 369.—View of Taylor mechanical stoker looking toward boiler front.

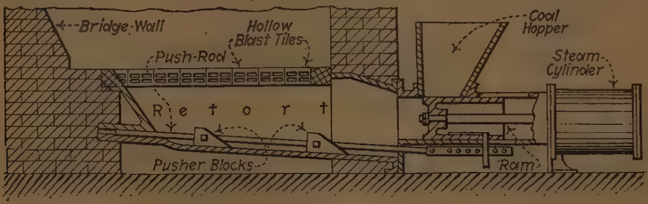


FIG. 370.—Section of Jones underfeed stoker.

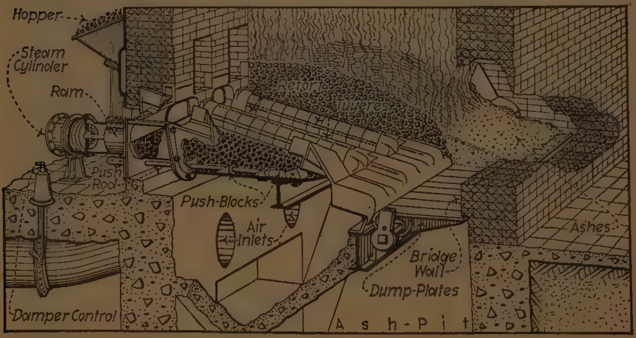


FIG. 371.—Jones multiple-retort underfeed stoker.

steps, upon which thefuel is pushed and over which it spreads by gravitation or other means. Otherwise (Figs. 368, 369, 370 and 371) the fuel bed may be continuously replenished by pushing the coal underneath the burning mass. This method requires no grate.

452. The different types of mechanical stokers are: (1) *Hand-operated* (Fig. 363). (2) *Chain-grate* (Fig. 364). (3) *Front-overfeed step-grate* (Figs. 366 and 367). (4) *Side-overfeed step-grate* (Fig. 365). (5) *Single-retort underfeed* (Fig. 370). (6) *Multiple-retort underfeed* (Figs. 368, 369 and 371). (7) *Sprinkling* (Fig. 372). (8) *Powdered fuel apparatus.*

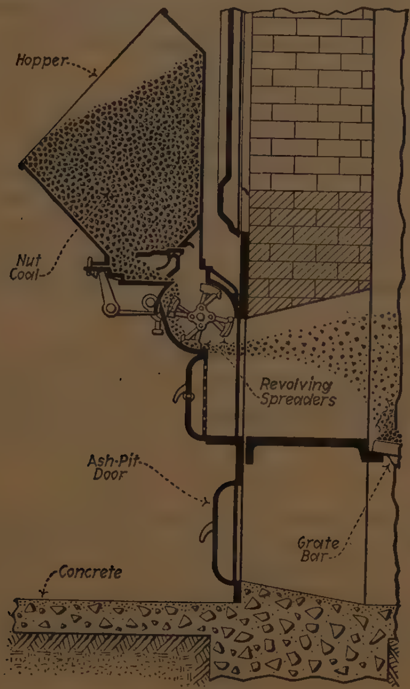


Fig. 372.—Swift sprinkling stoker.

453. Hand-operated mechanical stokers (Fig. 363) possess some of the advantages of automatic mechanical stokers. With a hand-operated stoker, the rated capacity of a boiler, as developed by hand-firing, may be exceeded by 30 to 75 per cent. The combined boiler-and-furnace efficiency may be improved. Cleaning of the fires may be rendered less difficult. Smokeless combustion may be secured. The cost of labor may be reduced.

NOTE.—Hand-operated stokers are especially adapted for small plants wherein mechanical stoking may be desirable, but where monetary considerations prohibit the installation of automatic stokers.

454. Automatic chain-grate mechanical stokers (Fig. 364) are, perhaps, more extensively used than those of any other type. The chain-grate, *C*, is propelled by a sprocket-drum, *D*. The drum is driven by means of a ratchet which is operated by the lever arm, *L*. The rod, *M*, which is driven by an eccentric on an overhead line-shaft, imparts an oscillating movement to the lever arm.

NOTE.—Chain-grate stokers may be successfully used for firing with unbriquetted lignite and coals which contain from 28 to 49 per cent. of volatile matter and from 10 to 20 per cent. of ash. They are especially designed for the burning of slack and screenings. Lump coal must be crushed before firing on a chain-grate. These stokers are well-adapted for the burning of middle-western coals. The maximum rate of combustion with a chain-grate is about 48 lb. of coal per sq.ft. of grate area per hour.

455. Automatic overfeed step-grate mechanical stokers of the front-feed (Figs. 366 and 367) and side-feed (Fig. 365) types are suitable for the firing of practically all grades of coal. A maximum of over 300 per cent. of the rated capacity of a boiler may be realized with these types.

NOTE.—The Roney front-feed step-grate stoker (Fig. 366) has rocking grate bars which are operated by an eccentric-propelled mechanism. The Wilkinson front-feed step-grate stoker (Fig. 367) has hollow grate bars through which blasts of steam are blown. The steam-jets are designed to force the draft and to prevent adherence of clinkers to the grate. The Detroit side-feed step-grate stoker (Fig. 365) has vibrating grate bars. These secure a continuous downward travel of the fuel.

456. Automatic underfeed single-retort and multiple-retort mechanical stokers (Figs. 368, 369, 370, and 371) feed the fire-bed from the under side. The coal is first deposited in a hopper or series of hoppers. A steam-operated ram or series of rams pushes the coal into one or more magazines or retorts. Forced draft is supplied through tuyeres which flank the retorts on both sides.

NOTE.—All grades of bituminous coal may be successfully fired with underfeed stokers. Installations which are designed to realize from 300 to 400 per cent. of the nominal boiler rating are common. A development on peak load of 600 per cent. of the nominal boiler rating has been

obtained. The considerable depth of green coal which interposes between the burning fuel and the retorts, and the currents of air issuing from the tuyeres, protect the apparatus from deterioration by heat.

457. Automatic sprinkling mechanical stokers are designed for the firing of coal in the form of finely-divided particles. The fuel is sprinkled or showered on the grate. Distillation of its volatile constituents is presumed to be effected rapidly enough to prevent the covering of the grate with green coal. Thus the fire-bed is continuously hot.

NOTE.—With the Swift sprinkling stoker (Fig. 372) the fuel is projected by a revolving element which is so arranged as to sprinkle it uniformly over the grate area. The grate is cleaned with the ordinary hand tools. The stoker is hung on hinges. It can be swung away from the boiler front like an ordinary door.

458. Apparatus for boiler-firing with powdered fuel is designed for blowing the coal into the furnace. The powdered or pulverized coal burns in a manner somewhat similar to the burning of a gas. The pulverizer may be a separate machine or it may be an integral part of the firing apparatus. Low grades of fuel, which might otherwise be unavailable, may be effectively burned when reduced to powder. Recent developments indicate that it may be profitable to pulverize even the better grades of coal.

NOTE.—The benefits which may be secured by burning fuel in powdered form are: (1) *Complete and smokeless combustion.* (2) *Facility in adjusting the rate of combustion to sudden changes of load.* (3) *Comparative lightness of the labor involved.* (4) *No stoker troubles.* (5) *Clean boiler room.* The disadvantages are: (1) *Cost of power for driving the pulverizer.* (2) *Liability of spontaneous combustion and explosions in stored masses of the powdered fuel.* (3) *Difficulty of cleaning out ash and slag.* (4) *Discharge of furnace refuse from the chimney.* (5) *High furnace-lining maintenance.*

QUESTIONS ON DIVISION 17

1. What are the principal functions of a mechanical stoker?
2. Are mechanical stokers advantageous in small plants? Why?
3. When might it be profitable to install a hand-operated stoker?
4. What are the main operating principles of mechanical stokers?
5. What is the distinction between a *hand stoker* and an *automatic stoker?*
6. What is the distinction between *front feed* and *side feed* stokers?
7. How does the boiler-forcing ability of underfeed stokers compare with that of over feed step-grate stokers?
8. Describe a sprinkling stoker.
9. What are the advantages and disadvantages of using powdered fuel?

DIVISION 18

PETROLEUM AND GASEOUS FUELS

459. Petroleum is a fossil oil, presumably of either animal or vegetable origin. It is found in pockets in the earth's interior. It is the only oil which, by reason of its abundance and comparatively low cost, can be profitably used for fuel in boiler plants.

NOTE.—The petroleums from the eastern oil fields of the United States contain a paraffin base. Their distillates are such that they are more valuable for other purposes than as boiler-fuel. The petroleums from the western and some of the southern oil fields contain an asphaltum base. These, either refined or in their crude, or natural, state, mainly supply the bulk of the steam-making fuel-oil which is used in the United States.

460. The chief advantages of petroleum fuel are: (1) *Its low cost of conveyance and storage.* Oil can be delivered

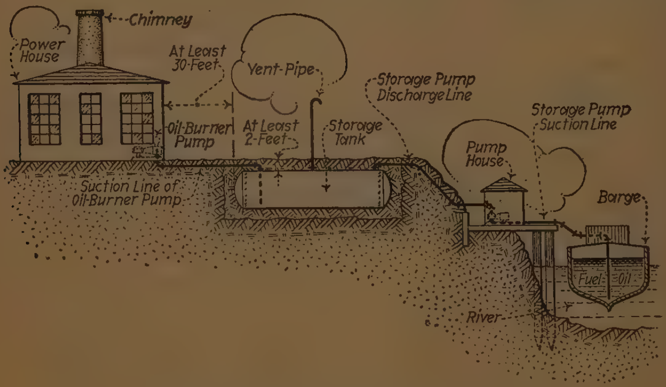


FIG. 373.—Conveyance and storage of fuel oil.

(Figs. 373 and 374) into underground storage tanks at a comparatively trifling cost. (2) *The relatively small storage room which it requires.* Approximately 50 per cent. more potential heat energy can be stored with oil than with coal in

a given space. (3) *The practically perfect combustion which it affords.* Oil requires less excess air for its combustion than does coal. It leaves no ash. It facilitates maintenance of a constant furnace temperature and elimination of smoke. It affords higher evaporative efficiencies than are attainable with coal. (4) *Its immunity from deterioration of calorific value while in storage.* (5) *Its immunity from spontaneous combustion while in storage.* (6) *The ease with which its intensity of combustion can be regulated to meet load fluctuations.* (7) *The saving of labor which its use affords.* (8) *The comparative cleanliness which attends its use.*

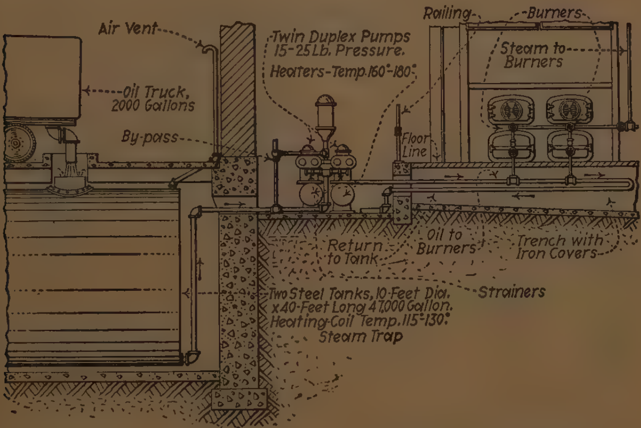


FIG. 374.—Typical oil-burning equipment for boiler plant.

461. The chief disadvantages of petroleum fuel are: (1) *The restrictions, with respect to locations of oil tanks, which are imposed by insurance and municipal regulations.* (2) *The liability of injury to boiler plates by local concentrations of its heating effect.* (3) *Its tendency to distil explosive vapors. But to explode the vapor it must be ignited. This should not be confused with spontaneous combustion.*

NOTE.—The specifications of insurance and municipal bodies generally require: (1) *That overground storage tanks be at least* 200 *feet from the nearest building.* (2) *That underground storage tanks* (Fig. 373) *be at least* 2 *feet below the surface and* 30 *feet from the nearest building.* But these stipulations are not (Fig. 374) universally inflexible.

462. The requisites of economical combustion of petroleum are: (1) *Thorough atomization of the oil.* (2) *Mixture of the atomized oil with the minimum quantity of air necessary for perfect combustion.* (3) *Radiation of heat from a refractory material in the furnace lining.* (4) *Completion of the combustion process before the gases make contact with the boiler heating surfaces.*

463. Oil-burners are designed to atomize the petroleum fuel which may be used in boiler furnaces. The atomization may be accomplished either by the centrifugal effect of rotatory propulsion in a mechanical device or by the disruptive effect of jets of steam (Figs. 375 and 376) or air.

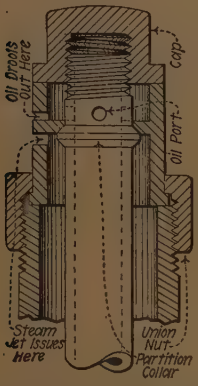


FIG. 375.—Tip of Peabody outside-mixing steam-atomizing fuel-oil burner.

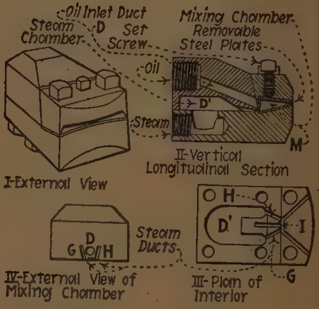


FIG. 376.—Details of tip of inside-mixing steam-atomizing oil burner.

NOTE.—STEAM-ATOMIZING BURNERS (Figs. 375 and 376) are used almost universally in stationary plants.

464. There are Two General Types of Steam-atomizing Burners.—(1) *The outside-mixing type* (Fig. 375) with which the oil and steam meet after issuance from the burner. (2) *The inside-mixing type* (Fig. 376) with which the oil and steam mingle within the burner.

NOTE.—The oil channels of inside-mixing burners (Fig. 376) are comparatively large. Hence, with such burners the oil requires only sufficient preheating to cause it to flow readily through the piping system. With outside-mixing burners (Fig. 375) the oil issues through narrow slits

Hence the oil should be preheated to at least 150 deg. Fahr. This may be done by passing it (Fig. 374) through an exhaust-steam heater. If the oil is preheated above 210 deg. Fahr., the water in it will vaporize. This will cause a sputtering of the flame. Provision should be made for draining the water of condensation from the heater steam-piping.

465. The steam consumption of steam atomizing oil-burners depends largely upon the skill exercised in handling the burners. It may range from 2 to 10 per cent. of the total quantity of steam generated.

466. The location and direction of the jet in an oil-burning boiler-furnace (Figs. 377 and 378) influence the effectiveness

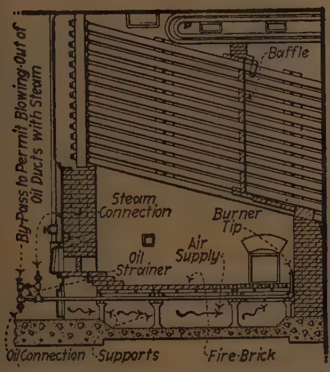


FIG. 377.—Proper furnace arrangement for horizontally-inclined water-tube boiler with vertical baffling.

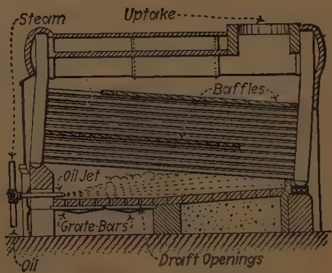


FIG. 378.—Proper furnace arrangement for either return tubular or horizontally-inclined water-tube boiler with horizontal baffling.

of the heat. However, if the proper quantity of air is supplied, these factors do not affect the combustion. Experience has demonstrated that the best results may be secured with a horizontal jet. It may be introduced from either the direction of the bridge wall (Fig. 377) or the boiler front (Fig. 378).

467. The pressure under which fuel-oil should be delivered to a burner depends upon the viscosity of the oil and the type of burner. It may range from about 5 to over 70 lb. per sq. in.

NOTE.—A relief valve (Fig. 374) set to the desired pressure, should be inserted in a cross-connection between the suction and delivery sides of the oil-pump. The system should be provided with an air chamber (Fig. 374) to absorb the pulsating effect of pump action.

468. Starting an oil-fire in a boiler-furnace may be done by first turning on just enough steam to blow through the burner and then gradually turning on the oil while holding the flame of a torch or some burning waste beneath the burner. When ignition occurs the oil and steam may be regulated to secure a proper mixture. If too much steam is supplied, it will be seen surrounding the burning spray and issuing from the chimney. If the steam supply is deficient, atomization will be incomplete. This will be indicated by scintillating sparks shooting from the burner. If the air supply is deficient, red flame and smoke will result. Correct proportion of oil, steam and air will produce a bright white flame and no smoke.

469. Gaseous boiler-fuels are chiefly in the form of natural gas and blast-furnace gas.

NOTE.—EFFECTIVE COMBUSTION OF NATURAL GAS requires that the number of burners used in each furnace = *rated boiler h.p.* ÷ 30. The combustion space should be about 2 cu. ft. per rated boiler h.p. If gas and coal are both used in the same furnace, the burners may be inserted through the fire-doors.

EFFECTIVE COMBUSTION OF BLAST-FURNACE GAS requires that the requisite proportions of both air and gas be regulated within the burner. The gas passages should be about 0.8 sq. in. per rated boiler h.p. This will require a gas pressure, at each burner, of about 2 in. of water. The pressure in the supply-main may be equivalent to a 6 to 8 in. column of water. The air passages should be from 0.75 to 0.85 sq. in. per rated boiler h.p. The furnace space should be from about 1.5 to 2 cu. ft. per rated boiler h.p. If the dust which the gas precipitates is allowed to accumulate in the furnace, it may fuse and become difficult to remove.

QUESTIONS ON DIVISION 18

1. What is the staple liquid-fuel in stationary boiler plants?
2. What are the chief advantages of petroleum fuel? The disadvantages?
3. Mention four conditions upon which economical combustion of petroleum is contingent.
4. Define an *inside-mixing oil-burner*. An *outside-mixing oil burner*.
5. How should an oil-fire be started?
6. What are the evidences of good combustion of oil? Of poor combustion?
7. What are the main requisites for effective combustion of natural gas? Of blast-furnace gas?

DIVISION 19

DRAFT AND ITS PRODUCTION AND MEASUREMENT

470. The function of draft is to force air to the fire and to carry away the gaseous products of combustion. Proper combustion in a furnace can occur only when an ample quantity of oxygen, which is contained in the air, is supplied to the burning fuel. If the supply of oxygen is insufficient, the combustion will be sluggish and inefficient—even with super-refined furnace construction and the most skillful stoking.

471. A definite meaning for the word "draft" has not been established rigidly. *Draft* is understood universally to relate to the movement of gases through a furnace, boiler and chimney. But sometimes it is used to indicate the volume of the gases moved. Again, it is employed frequently to denote the air pressure which produces the movement. In this book, "draft" will be applied to designate the quantity of air which is forced through a furnace in a given time. The term *draft pressure* will imply the pressure which causes the gases to move.

EXAMPLE.—The *draft* may be ample, when sufficient air is supplied to the furnace for combustion, even though the *draft pressure* is small, as shown by a draft-pressure gage which reads only a ½ in. water column.

472. Chimney draft is due to a pressure as indicated in Figs. 379 and 380. The impression that it is due to a vacuum is erroneous. Why this is true will be explained later. A draft-pressure gage reading (Fig. 381) indicates the tendency or pressure of the cold outside air to force its way into the furnace, boiler setting, breeching or chimney.

473. Draft Pressure may be Produced either Naturally or Artifically.—Only chimney, or *natural draft* is discussed in this Div. *Artificial draft* is discussed in Div. 21. A classification may be arranged thus:

(1) NATURAL DRAFT

(A) *Produced by the natural draft of a chimney.*

(2) ARTIFICIAL DRAFT

(A) *Steam jet*

(a) Induced

(b) Forced

(B) *Mechanical draft by a fan or blowing machine.*

(a) Induced

(b) Forced

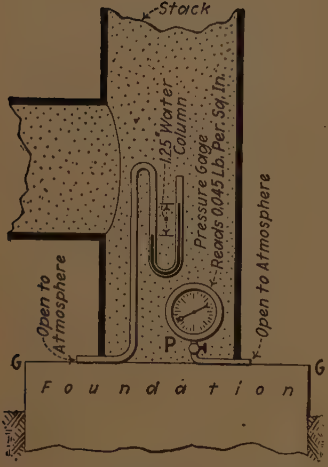


FIG. 379.—Pressure gages inside stack.

FIG. 380.—Vacuum gage outside stack.

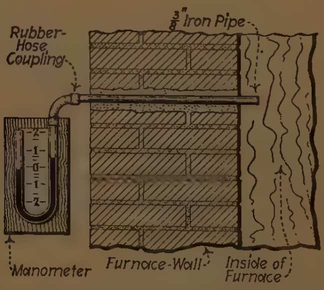


FIG. 381.—Manometer draft gage arranged for indicating difference in pressure between inside and outside of boiler setting.

474. The function of a chimney is twofold: (1) *It produces the draft pressure, whereby the draft is forced through the furnace, fuel and setting.* The air which carries the oxygen, necessary for the proper combustion—burning—of the fuel, is thereby

furnished to the fuel bed. (2) *It carries the products of combustion to such a height, before discharging them, that they will not be objectionable or injurious to surroundings.*

475. The basic principle of natural or chimney-draft pressure is thus: When a lighter gas is submerged in a heavier one, the lighter gas is forced upward by the heavier A hot-air balloon ascends in the cooler atmosphere; similarly a cork, which is submerged in water, rises. It is due to the same fundamental causes that a chimney produces the draft pressure which forces the draft through the boiler-furnace and setting.

EXAMPLE.—A cubic foot of air at a temperature of 60 deg. Fahr., weighs about 0.08 lb. A cubic foot of air at 600 deg. Fahr., weighs about 0.04 lb. Hence, a cubic foot of 600-deg. air which is submerged in an atmosphere of 600-deg. air, will be forced upward with a force of: $0.08 - 0.04 = 0.04$ *lb.*

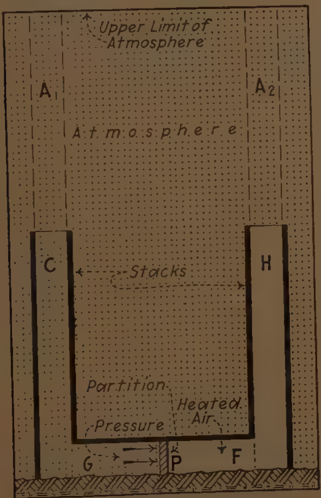


FIG. 382.—Illustrating the principle of chimney draft.

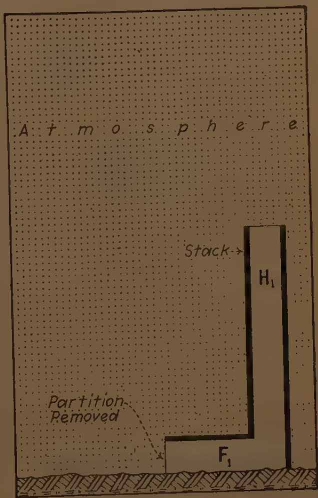


FIG. 383.—Furnace and stack.

476. How a chimney produces a draft pressure may be understood from a consideration of Figs. 382, 383 and 384.

EXPLANATION.—In Fig. 382, stacks *C* and *H* are of identical dimensions and construction. *CG* is filled with the cool air of the surrounding atmosphere. This *CG* air is at the same temperature as that of the surrounding atmosphere. *HF* is filled with hot air. The volume of hot air

in H, because of its lower density (see the author's PRACTICAL HEAT), weighs less than the equal volume of cool air in C. The equal cool-air columns A_1 and A_2, each extending vertically upward to the limit of the atmosphere counterbalance one another. Hence (see preceding Sec.) the heavy volume C tends to force the lighter volume H up out of the stack. Thus a pressure is exerted against partition P. *The force, in pounds, imposed against* P = *(lb. weight of* C*)* − *(lb. weight of* H*).*

Neither the volume of hot air in the horizontal passage F nor that of cool air in G are factors in the problem, since neither increases the *vertical* heights of the air columns.

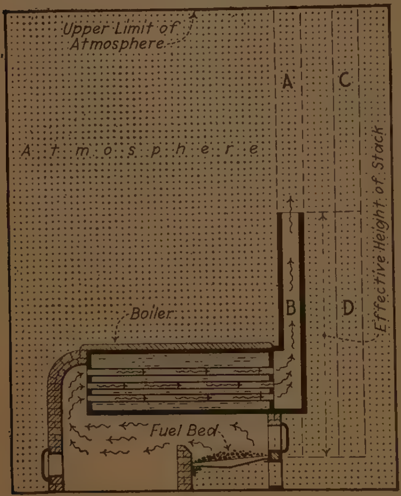


FIG. 384.—Draft-pressure principles applied to an actual boiler.

If CG were removed (Fig. 383) and the entering cool air were continuously heated in F_1, a continuous current of air would, obviously, be forced upward through F_1H_1. The removal of stack CG has not, since CG contained only air at atmospheric temperature, affected the elements of the situation. Fig. 384 illustrates the application of the principle to an actual boiler and stack. In Fig. 384, the *pounds draft pressure impressed against the grate* = *(lb. weight of cool-air column* D*)* − *(lb. weight of hot air column* B*).* D and B both have the same cross-sectional area. The height of columns B and D is the vertical distance between the top of the stack and the bottom of the grate.

477. Draft pressure is measured in "inches of water column" in practice because this is the most convenient unit. It could, if desirable or convenient, be measured in any unit of *pressure per unit area* such as "pounds per square inch."

EXAMPLE.—A draft-pressure gage reading of 2 *in. water column* means that the draft pressure tending to force the outside air into the stack or boiler, at the point at which the reading is taken, is just sufficient to support a column of water 2 in. high.

478. An elementary manometer or draft-pressure gage (Fig. 381) is merely a glass tube of any convenient diameter and having a "U" bent in one end. The U-portion is filled partially

with water. One end of the tube is extended into the enclosed space, the draft pressure into which it is desired to measure.

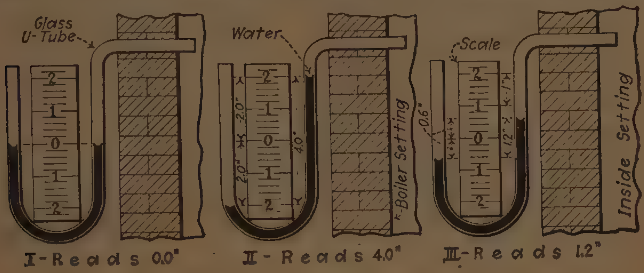


FIG. 385.—Examples in reading manometer draft gages.

The other end is open to the atmosphere. When there is no difference in pressure between the two ends of the tube, the water will rest at the same level Fig. 385, I) in both legs. If the atmospheric pressure tends to force air into the enclosed space, the water in the leg which connects into the space is

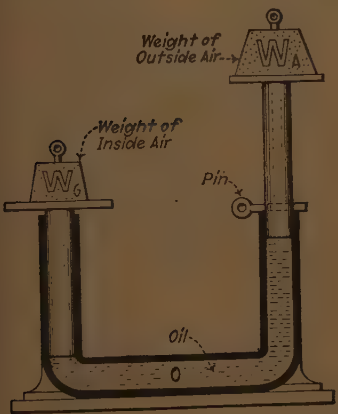


FIG. 386.—The principle of draft. (If the pin is removed, W_A will force W_G up, just as the cold outside air forces up the water in one leg of a manometer.)

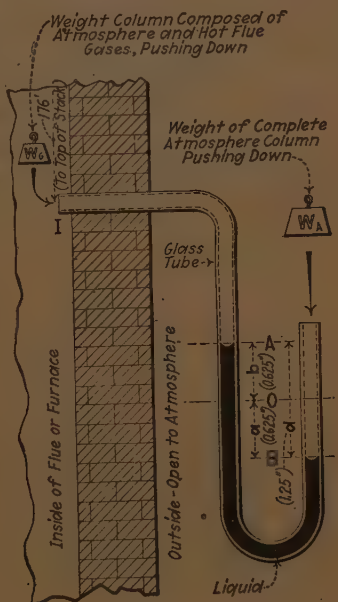


FIG. 387.—The principle of the manometer draft gage.

forced up (Fig. 385, II and III) correspondingly. The weight of the cool-atmosphere column (W_A, Figs. 386 and 387) acts

against the weight of the lighter, hot-air column and forces it up, until the unbalanced height of the water column just equals the difference in the weights.

479. The total draft pressure, sometimes called the *Theoretical Maximum Static Draft Pressure,* developed by a chimney is the total pressure which results due to the difference in the weights of the column of hot flue gas inside the chimney and a column of the outside air of the same area and height.

EXAMPLE.—The total draft pressure will be indicated by a draft-pressure gage, which is located at the grate level, when the ash pit door is closed and no flue gases are flowing. In Fig. 388 and Table 480, IV (which will be discussed later) the total pressure is 1¼ in. (1.25 in.) water column, as indicated by gages *B*, *E* and *V*. Fig. 389 shows conditions with the ash pit door open.

480. Table Showing Chimney Draft Pressure, Draft-pressure Drop and Available Draft Pressure.—(The values in this table have been computed for an imaginary exagger-

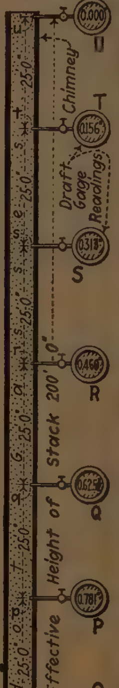
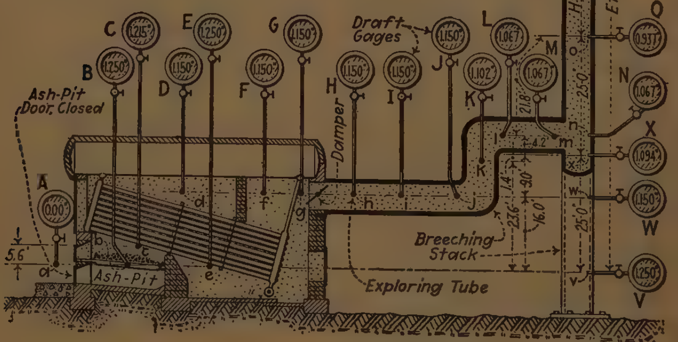



FIG. 388.—Draft-gage readings for boiler setting and stack with fire door closed air tight (this shows a theoretical, ideal condition unattainable in practice).

ated set of conditions, Fig. 389, to illustrate the principles involved.)

I Element of flue gas path		Draft-pressure gages: II Identifying letter	Draft-pressure gages: III Assumed height of exploring tube above grate (feet)	*IV Elevation draft pressure (inches water column) due to hot gas column	Ash-pit door open (all values in inches water column). Drop in draft pressure due to friction and velocity: V Between successive tube locations		VI Total up to designated location	Available draft pressure: VII Between successive tube locations		VIII Total up to designated location VIII = IV − VI	Identifying letter
Outside		A	0.0	1.250			1.250			0.000	A
Boiler	Ash pit	B	0.0	1.250	*a* to *b*	−0.010	1.240	*a* to *b*	+0.010	0.010	B
	Furnace	C	5.6	1.215	*b* to *c*	−0.440	0.800	*b* to *c*	+0.405	0.415	C
	End 1st pass	D	16.0	1.150	*c* to *d*	−0.130	0.670	*c* to *d*	+0.065	0.480	D
	End 2d pass	E	0.0	1.250	*d* to *e*	−0.130	0.540	*d* to *e*	+0.230	0.710	E
	End 3d pass	F	16.0	1.150	*e* to *f*	−0.130	0.410	*e* to *f*	+0.030	0.740	F
	Inside damper	G	16.0	1.150	*f* to *g*	−0.010	0.400	*f* to *g*	+0.010	0.750	G
Breeching		H	16.0	1.150	*g* to *h*	−0.015	0.385	*g* to *h*	+0.015	0.765	H
		I	16.0	1.150	*h* to *i*	−0.014	0.371	*h* to *i*	+0.014	0.779	I
		J	16.0	1.150	*i* to *j*	−0.014	0.357	*i* to *j*	+0.014	0.793	J
		K	23.6	1.102	*j* to *k*	−0.065	0.292	*j* to *k*	+0.017	0.810	K
		L	29.2	1.067	*k* to *l*	−0.065	0.227	*k* to *l*	+0.030	0.840	L
		M	29.2	1.067	*l* to *m*	−0.014	0.213	*l* to *m*	+0.014	0.854	M
Chimney	Active	N	29.2	1.067	*m* to *n*	−0.000	0.213	*m* to *n*	+0.000	0.854	N
		O	50.0	0.937	*n* to *o*	−0.030	0.183	*n* to *o*	+0.100	0.754	O
		P	75.0	0.781	*o* to *p*	−0.031	0.152	*o* to *p*	−0.125	0.629	P
		Q	100.0	0.625	*p* to *q*	−0.030	0.122	*p* to *q*	−0.126	0.503	Q
		R	125.0	0.469	*q* to *r*	−0.031	0.091	*q* to *r*	−0.125	0.378	R
		S	150.0	0.312	*r* to *s*	−0.030	0.061	*r* to *s*	−0.127	0.251	S
		T	175.0	0.156	*s* to *t*	−0.031	0.030	*s* to *t*	−0.125	0.126	T
		U	200.0	0.000	*t* to *u*	−0.030	0.000	*t* to *u*	−0.126	0.000	U
	Inactive†	V	0.0	1.250	*u* to *v*	+0.213	0.213	*u* to *v*	+1.037	1.037	V
		W	16.0	1.150	*v* to *w*	−0.000	0.213	*v* to *w*	−0.100	0.937	W
		X	25.0	1.094	*w* to *x*	−0.000	0.213	*w* to *x*	−0.056	0.881	X
		N	29.2	1.067	*x* to *m*	−0.000	0.213	*x* to *n*	−0.027	0.854	N

* Since the *total draft pressure* developed by this 200 ft. high chimney is 1.25 in., the drop due to decreasing height of flue-gas column, per foot height, is: 1.25 ÷ 200 = 0.006,25 *in. water column.*

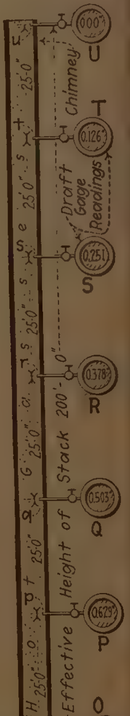
† It is here assumed that the INACTIVE portion of the chimney contains flue gases at the same temperature as that of those in the ACTIVE portion.

481. The formula for computing the chimney height necessary for the development of a given draft pressure is stated below. Its derivation is too lengthy for inclusion here. The formula is merely an expression, for the difference in weight of unit columns of *hot chimney gas* and of *cool outside air*, reduced to pressure, in inches water column:

$$(65)\quad P_D' = 0.52 L_h P_2 \left(\frac{1}{T_o + 460} - \frac{1}{T_G + 460}\right) = \left(\begin{array}{c}\text{total draft pres-}\\ \text{sure, inches}\\ \text{water column}\end{array}\right)$$

$$(66)\quad L_h = \frac{P_D'}{0.52 P_2 \left(\dfrac{1}{T_o + 460} - \dfrac{1}{T_G + 460}\right)} = \text{(height, feet)}$$

Wherein: P_D' = total draft pressure, in inches water column, exerted at the base of the chimney, or portion thereof, of height L_h.



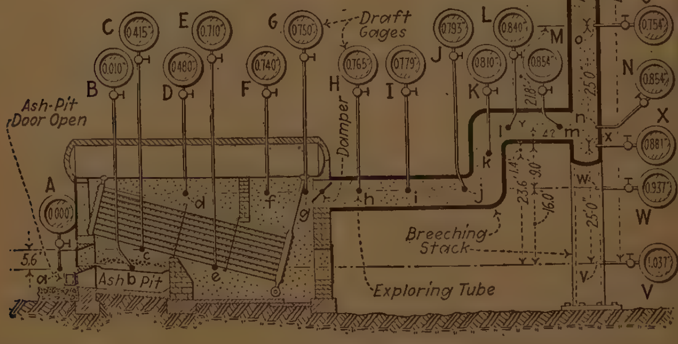


FIG. 389.—Showing draft-gage readings in a specific case with ash-pit open.

L_h = height of the chimney—or portion thereof, under consideration, in feet. P_2 = pressure of the atmosphere

at the altitude at which the chimney is installed, in lb. per sq. in. = 14.7 lb. per sq. in. at the sea level. T_o = average temperature of outside air, in degrees Fahrenheit; this is usually taken, in the temperate zone, as about 60 to 65 deg. T_G = average temperature of chimney gases, in degrees Fahrenheit, usually taken as about 500 to 600 degrees.

EXAMPLE.—What total draft pressure will a chimney, which is located at sea level and 200 ft. high, produce if the average temperature of the flue gases is 445 deg. Fahr. and an average outside-air temperature of 60 deg. Fahr. is assumed? SOLUTION.—Substitute in For. (65): $P_D' = 0.52 \times L_h \times P_2\{[1/(T_o + 460)] - [1/(T_G + 460)]\} = 0.52 \times 200 \times 14.7\{[1/(60 + 460)] - [1/(445 + 460)]\} = 1.25$ *in. water column.* Note that the proportions of this chimney correspond with those in the example of Fig. 388 and Table 380.

NOTE.—THE HEIGHT OF A CHIMNEY DETERMINES THE DRAFT PRESSURE WHICH IT WILL DEVELOP under given altitude, and outside-air and flue-gas temperature conditions. To develop a certain draft pressure a chimney should be the same height regardless of the number of boilers which it serves. But the greater the number of boilers served—the greater the amount of coal burned—the greater the flue area should be. This situation is explained in Sec. 492, wherein is given the formula for computing flue area.

482. There is a Drop in Draft Pressure when Flue Gases Flow in a Chimney.—When the ash-pit door is closed—when there is no flue-gas flow—there is no drop. Under this condition, assuming that the setting and chimney are air tight, a draft-pressure gage (*B*, Fig. 388), which is located at the grate level, will read the *total draft pressure* (Sec. 479) which the stack develops. In Fig. 388, this is 1.25 in. water column. When flue gases are flowing, the grate-level draft-pressure-gage reading (*B*, Fig. 389) will, because of drop, be less than the total draft pressure. In Fig. 389, it is 0.10 in. Probable values of drop in chimney draft pressure may be predicted, as explained hereinafter, by using data (Table 485) which are based on experience.

NOTE.—Drop in draft pressure is similar to the drop in hydraulic pressure which occurs in a pipe when water flows therein. It is similar to the drop in electric pressure (voltage) in an electric circuit which is occasioned by a flowing electric current.

NOTE.—DRAFT-PRESSURE DROP is a loss in draft pressure which is caused by: (1) *The frictional resistance offered by the interior surfaces of*

the chimney and gas passages to the flue-gas flow; columns V and VI in Table 480. (2) *The imparting of velocity to the flue gases;* columns V and VI in Table 480. In chimney-design practice, cause (2) is usually negligible. Hence, in Table 480, (1) and (2) are combined.

483. The available draft pressure, at any location along the flue-gas path, is the draft pressure which is unexpended, remaining or available at that location. Draft pressure gages indicate available draft pressures. To obtain the available draft pressure at any point along the flue-gas path, subtract from the *total draft pressure* (Sec. 479) developed by the stack at that location the *total draft pressure drop* up to that point.

Example.—In Table 480 (see also Fig. 389), the total drops are given in Column VI. In column VII the available draft pressures are recorded. The *available draft pressure* (*i.e.*, the draft-pressure gage reading) at any location = (*Total Draft Pressure at That Location*) − (*Total Drop To That Location*). Thus, at location *G*, *available Draft Pressure* = 1.150 − 0.400 = 0.750 *in. water column.*

484. Drop in available draft pressure is the drop or decrease in the available pressure at successive locations along the flue-gas path. Drops in available-draft pressure between different locations may be obtained by taking the difference between the draft-pressure-gage readings taken at those locations. Tables, such as that which follows (Table 485) which show approximate drops in pressure along the flue-gas path, practically always give *drops in available draft pressure.* Such tabulated values (Table 485) are based on draft-pressure-gage reading observed in operating installations.

Examples.—In Table 480, which gives values for the conditions of Fig. 389, the *drops in available draft pressure,* between the different tube locations, are listed in Column VIII. These between-location drops are merely the differences between the successive available-draft values of Column VII. Note that from *A* to *M* the drops are positive(+), while from *N* to *U* they are negative. This situation will be referred to later. The total available-draft-pressure drop from *A* to *M* is 0.854 − 0.000 = *in.* water column. Also, the total available draft pressure drop from *N* to *U* is 0.854 in. water column.

485. Table Indicating Approximate Drops in Available Draft Pressure which may be Expected in Practice.—The values shown are averages of many determinations. While,

in unusual cases, drops differing widely from those tabulated may be encountered, the values given are, ordinarily, sufficiently accurate for estimating the height of a chimney required to satisfy a given set of conditions. Values given are for normal boiler load on the basis of the boiler rating. The drops increase as the load which the boiler is carrying increases.

<table>
<tr><th>No.</th><th colspan="2">Element of flue-gas path</th><th>Approximate available-draft drop (In inches water column)</th></tr>
<tr><td>1</td><td rowspan="5">Boiler</td><td>Ash pit</td><td>Often disregarded. Should not exceed 0.01 in.</td></tr>
<tr><td>2</td><td>Fuel bed and furnace</td><td>Depends on kind and size of coal, pounds burnt per hour, design of furnace, etc. For typical values, see Fig. 390.</td></tr>
<tr><td>3</td><td>(a) First pass</td><td rowspan="3">Depends on: (1) Type of Boiler. (2) Method of Baffling. May vary between 0.10 and 1.00 in. Often assummed to be about 0.40 in. total, from furnace to through last pass.</td></tr>
<tr><td>4</td><td>(b) Second pass</td></tr>
<tr><td>5</td><td>(c) Third pass</td></tr>
<tr><td>6</td><td rowspan="2">Smoke conduit (Breeching)</td><td>Straight runs</td><td>Unlined sheet steel, 0.001 in. per foot length. Brick or masonry, lined, 0.002 in. per foot length.</td></tr>
<tr><td>7</td><td>Turns or elbows</td><td>Each right-angle turn, unlined steel or masonry—lined, 0.05 in.</td></tr>
<tr><td>8</td><td colspan="2">Damper</td><td>Small. Can usually be disregarded.</td></tr>
<tr><td>9</td><td colspan="2">Economizer</td><td>Varies (see Sec. 596) over a considerable range. Ordinarily is between 0.10 in. and 0.25 in.</td></tr>
<tr><td>10</td><td colspan="2">Chimney</td><td>Is for a chimney of the most economical height and diameter equal to 20 per cent. of the Total Draft Pressure (Sec. 479) developed by the chimney, or by the portion of the chimney under consideration.</td></tr>
</table>

486. The Drop in Available Draft Pressure through any Element of a Flue-Gas Route Represents the Draft Pressure Necessary to Force the Flue Gases through that Element.—Hence, to determine the effective or net draft pressure which a chimney for a given installation must produce at its base, it is merely necessary to add together the available-draft-pressure drops through the furnace, setting and smoke conduit. Their sum, in inches water column, will be equal to the net or effective draft pressure which the chimney must develop. How this principle is applied in actual chimney design is explained hereinafter.

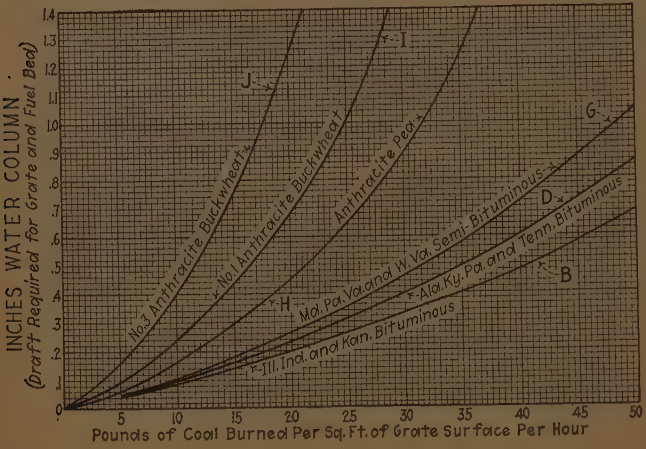


FIG. 390.—Draft pressure required to force air through furnace and full bed for various kinds of coal at different rates of combustion (from "Steam").

487. The "smoke-conduit connection," as the term is used herein, is the location where the smoke conduit from the boiler or boilers joins the chimney. In Fig. 389, the *smoke-conduit connection* is at *m*.

488. The effective draft pressure of a chimney is the available draft pressure (Sec. 483) developed by the chimney at the smoke-conduit connection, when the flue gases are flowing. It is that portion of the total draft pressure, developed by the chimney from the smoke-conduit connection up, which is not lost in the chimney in overcoming friction and

in imparting velocity to the flue gases. Therefore, it is the draft pressure which is effective in pulling the flue gases through the boiler and smoke conduit.

(67) *Effective Draft Pressure* = (*Total Draft pressure at the smoke-conduit connection*) − (*Drop in draft pressure in the chimney, from the smoke-conduit connection up*).

EXAMPLE.—In Fig. 389 and Table 480 the *effective draft pressure*, shown at M and N, is 0.854 in. water column. That is: 1.067 − 0.213 = 0.854 *in.* In Fig. 391, the "effective draft pressure" (at E) is 1.00 in. water column.

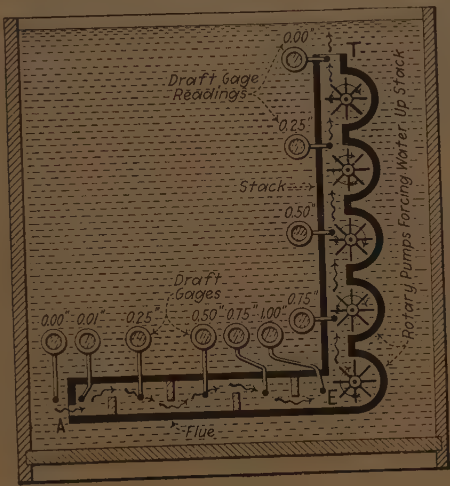


FIG. 391.—Illustrating the principle of "loss" or "drop" in draft pressure.

EXPLANATION.—A chimney in action is analogous to a vertical tube (TE, Fig. 391) along which operating centrifugal pumps are arranged, the whole being submerged in a vessel of water. The water in the vessel is analogous to the atmosphere. The hydraulic pressure developed by the pumps is analogous to the draft pressure developed by the hot gases in a chimney. The current of water, circulated through AET by the pumps, is analogous to the flue gases which are circulated by a chimney. The available pressure increases from the top, T, of the stack down to E, where the *effective pressure* is 1.00 in. From E, the available pressure decreases along EA to 0.00 in. at A.

In AE no propelling pressure is developed. Similarly, no draft pressure is developed in the horizontal portions of a flue-gas path. Practically no draft pressure is developed in a boiler setting because its vertical

height is small as compared to that of a chimney. The pressure developed in ET pulls the water through AE. There is a pressure drop in AE, as shown, which is due to friction. The effective pressure (which is the available pressure at E) must be equal to the total available-pressure drop through AE. Otherwise the pumps could not pull the water through AE.

489. The Sum of the Available-draft-pressure Drops, Along the Flue-gas Path from the Ash-pit Door to the Smoke-conduit Connection, must equal the effective Draft Pressure. —This law holds for any operating chimney. It means this: Any satisfactory chimney must be of sufficient height that it will develop not only a great enough draft pressure to circulate the flue gases through itself but in addition it must provide enough excess draft pressure—effective draft pressure—at the smoke-conduit connection to pull the flue gases through the boilers and beechings.

NOTE.—It follows from the above that to determine the *effective draft pressure* which a chimney for a given installation should develop, it is merely necessary to add together all of the available-draft pressure drops which occur in the boiler, setting and smoke conduit. The effective draft pressure must equal their sum. Following examples illustrate this principle.

490. To compute the chimney height required for a given installation, the procedure is as follows: *First,* determine the total draft pressure which is necessary, by using the following formula, the derivation of which is given below.

$$P''_D = 1.25(A.D.P.D._{BC}) \qquad \text{(in. water column)} \tag{68}$$

Wherein P''_D = total draft pressure which the chimney must develop, from the smoke-conduit connection to its top, in inches water column. $A.D.P.D._{BC}$ = available-draft-pressure drop (Sec. 484) through the boiler and breeching up to the smoke-conduit connection, in inches water column.

Then, to ascertain the height which the chimney should have above the smoke connection to produce the total draft pressure, which is necessary, substitute the value for P''_D determined with For. (68) for P'_D in For. (66) and solve. See following example.

EXAMPLE.—What height should a chimney be to provide the draft for a boiler installation, when conditions are assumed as follows: Installation is located at sea level. Hence, $P_2 = 14.7$. Available-draft drops: *ash pit*, 0.010 *in.*; *furnace and fuel bed*, 0.405 *in.*; *first second and, third passes*, 0.335 *in.*; *breeching*, 0.104 *in.*; average flue gas temperature = 445 deg. Fahr. Average outside-air temperature = 60 deg. Fahr.

SOLUTION.—First, substitute in For. (68): $P''_D = 1.25(A.D.P.D_{BC}) = 1.25 \times (0.010 + 0.405 + 0.335 + 0.104) = 1.25 \times 0.854 = 1.067$ *in. water column* = *total draft pressure which the chimney must develop.* Now by applying For. (66), determine the chimney height necessary to develop a total draft pressure of 1.067 in water column under the conditions of this example: $L_h = P''_D/0.52\, P_2[1/(T_o + 460) - 1/(T_G + 460)] = 1.067 \div (0.52 \times 14.7)[1 \div (60 + 460) - 1 \div (445 + 460)] = 174.6$ ft. = *height of chimney required above the smoke-conduit connection.* Note that this example applies (with negligible error) to the conditions of Table 480 and Fig. 389 for which the $A.D.P.D_{BC} = 0.854$ in. and the chimney height above the center of the smoke conduit connection = 200 − 29.2 = 170.8 ft.

THE DERIVATION OF THE ABOVE FORMULA is this: It follows from the statements of preceding Sec. 489 that:

(69) $$E.D.P. = A.D.P.D_{BC} \qquad \text{(in. water column)}$$

Wherein, $E.D.P.$ = effective draft pressure, as defined in Sec. 488, in inches water column. $A.D.P.D._{BC}$ has same meaning as is specified above. Now, as stated in Table 485, the available-draft-pressure drop in a chimney may be taken as 20 per cent. of the total draft pressure developed therein. That is, since 20 per cent. of the total draft pressure is consumed in the chimney in overcoming friction and imparting velocity, only 100 − 20 = 80 per cent. of the total pressure is available as *effective* at the smoke-conduit connection. Hence:

(70) $$E.D.P. = 0.8\, P''_D \qquad \text{(in. water column)}$$

Now, substituting the value from (70) for its equivalent in (69):

(71) $$0.8\, P''_D = A.D.P.D._{BC} \qquad \text{(in. water column)}$$

Simplifying:

(72) $$P''_D. = \frac{A.D.P.D_{BC}}{0.8} = 1.25(A.D.P.D._{BC}) \qquad \text{(in. water column)}$$

491. The flue area which a chimney should have should be based on the volume of gas which must be conducted from the boilers. Obviously, the pounds of coal burnt per hour is an important consideration. Furthermore, the flue area of a chimney should be large enough that the gases will be conducted in it without excessive pressure drop (Sec. 484). Otherwise, the effective draft pressure which the chimney develops will be insufficient.

492. A formula for computing chimney-flue area follows. This (as are practically all other chimney-flue-area formulas) is based on practical experience rather than on mathematical analysis. A flue proportioned in accordance with it, will convey the gases with about the 20 per cent. drop which is specified in Table 485.

(73) $$A = \frac{W_c}{12\sqrt{L_h}} \quad \text{(area, sq. ft.)}$$

(74) $$d = \sqrt{\frac{W_c}{9.43\sqrt{L_h}}} \quad \text{(diameter, ft.)}$$

Wherein: A = cross-sectional flue area of chimney, in square feet. L_h = height of chimney, above smoke-conduit-connection, in feet as computed by For (66). W_c = coal burnt per hour, in pounds. d = diameter of chimney flue, in feet.

Note.—In Using The Above Formulæ For Square Chimneys, the corners thereof should be neglected. The area taken is that of a circle which would just fit inside the chimney.

Example.—What should be the cross-sectional area of the flue in a chimney which is 140 ft. high and which conducts the gases from a battery of boilers that burn 4,000 lb. of coal per hr. Solution.—Substitute in For. (73): $A = W_c/(12\sqrt{L_h}) = 4{,}000 \div (12 \times \sqrt{140}) = 4{,}000 \div 142.2 = 28.1$ *sq. ft.* Its diameter would be, substituting in For. (74), $d = \sqrt{W_c/9.43\sqrt{L_h}} = \sqrt{4{,}000 \div 9.43 \times \sqrt{140}} = 5.98$ *ft.* = 5 *ft.* 11¾ in.

493. The application of the previously-discussed principles to the design of an actual boiler-plant chimney will now be explained with an illustrative example, which is taken partly from Steam.

Example.—Proportion a chimney for a battery of boilers, rated at 2000 boiler h.p., which are equipped with stokers. They burn Maryland semi-bituminous coal that will evaporate 8 lb. of water, from and at 212 deg. Fahr., per pound of fuel. The ratio of boiler-heating surface to grate surface is 50: 1. The unlined-steel smoke conduit is 100 ft. long and contains two right-angle bends. The chimney should be capable of handling overloads of 50 per cent. The rated horse power of the boilers is based on 10 sq. ft. of heating surface per h.p. The chimney will be located at an altitude 2,000 ft. above sea level where the atmospheric pressure is 13.57 lb. per sq. in. The average outside-air temperature may be taken as 60 deg. and the flue-gas temperature, at the 50 per cent.

overload, as 550 deg. Fahr. The combined grate area of the boilers is 400 sq. ft.

SOLUTION.—The *total boiler heating surface* = 10 × 2,000 = 20,000 *sq. ft.* Hence, the *grate surface* = 20,000 ÷ 50 = 400 *sq. ft.* The *total coal burnt per hour* (See Sec. 402) = (2,000 × 34.5) ÷ 8 = 8624 *lb.* Therefore the *coal burnt per hour per sq. ft. of grate surface* = 8624 ÷ 400 = 22 *lb.* (approx.). At 50 per cent. overload, the combustion rate will be about 60 per cent. greater: 22 × 1.60 = 35 *lb. per sq. ft. of grate surface per hour.*

Now determine the $A.D.P.D._{BC}$: Refer to Table 485:

	Inches water column
Drop through furnace and fuel bed with Maryland Semi-bituminous coal burned at the rate of 35 lb. per sq. ft. of grate surface per hour as taken from the graph of Fig. 390	0.6
Drop through passes, from Table 485	0.4
Drop through 100 ft. of unlined smoke conduit (see Table 485) = 0.001 × 100 =	0.1
Drop through two right-angle turns (see Table 485) = 0.05 × 2 =	0.1
Total Available-draft-pressure Drop Through Boiler and Smoke Conduit	1.2

Next, determine the total draft pressure necessary by substituting in For. 68: $P''_D = 1.25\ (A.D.P.D._{BC}) = 1.25 \times 1.2 = 1.5$ *in. water column.* Now find the height of chimney required to develop a total draft pressure of 1.5 *in.* Substitute in For. (66) $L_h = P'_d/\{0.52P_2[1/(T_o + 460) - 1/(T_G + 460)]\} = 1.5 \div \{0.52 \times 13.57\ [1 \div (60 + 460) - 1 \div (550 + 460)]\} = 1.5 \div \{7.06 \times (0.001{,}925 - 0.000{,}991)\} = 1.5 \div (7.06 \times 0.000{,}934) = 228$ *ft.* = *chimney height above smoke conduit connection.*

The flue area of the chimney should be: $A = W_c/12\sqrt{L_h} = 8624 \div (12 \times \sqrt{228}) = 8624 \div (12 \times 15.1) = 8624 \div 181.3 = 47.5$ *sq. ft.* The diameter would be: $d = \sqrt{W_c/9.43\sqrt{L_h}} = 7.8$ *ft.*

494. The draft pressure gages which are used in practice differ from the elementary forms, shown in Figs. 381, 385 and 387, which would not be sufficiently accurate because of the short lengths of their scales. In the manometer-type "differential" gages (Fig. 392), ample accuracy is attained by inclining one leg of the gage-glass tube and using in it a light oil instead of water. Thus a long scale is provided. The inclined tube permits the liquid to move the same vertical height as when the tube is vertical. But the distance moved through is generally about 10 times as great with the inclined

as with the vertical tubes. Thus the lengths of the scale divisions are multiplied by 10. This renders the inclined-tube instruments easier to read. The long inclined scale may be so divided that differences of draft pressure of 0.01 in. water column may be read easily. In the aneroid-type gages (Figs. 393, 394, 395, 396 and 397) the pointer is actuated, through a lever system, by the movement of the elastic top of a metallic box. From the interior of the box, a tube connects with the boiler space in which the draft pressure is to be measured. Aneroid gages may be either indicating or graphic as shown by the illustrations.

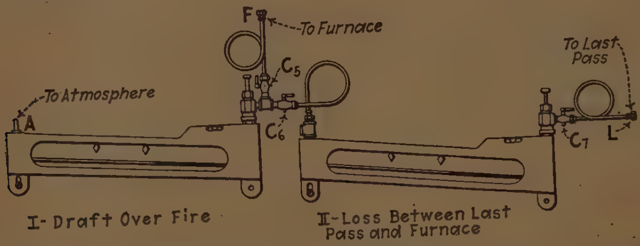


FIG. 392.—Two draft-pressure gages arranged to show: (1) available draft pressure over fire and (2) drop in available draft between last pass and furnace. (If it is desired, in forced-draft installations, to show the draft pressure in the ash-pit, the air vent *A* may be connected with the closed ash-pit, a three-way cock, similar to those shown, being installed in the connecting pipe.)

NOTE.—Three-way cocks (Fig. 398) may be provided on draft-pressure gages (C_5, C_6 and C_7, Fig. 392) whereby the gage may be connected either to the atmosphere or to the exploring tube. All of the aneroid gages shown are provided with three-way cocks.

495. In locating draft-pressure gages, they should always be so placed that they can be seen by the fireman without effort. When so located the fireman will learn to fire by the draft-pressure gage rather than by the steam gage. A good location is directly on the boiler front above and to one side of the fire door.

496. In installing draft-pressure gages, they may be mounted on the boiler front on a piece of well-seasoned wood (Fig. 399) which is backed by a slab of asbestos board. Or they may be supported (Fig. 400) on metal studs which permit a free circulation of air around the gage. Be certain that the gage is set level.

497. Draft-pressure gage piping may be ⅛ or ¼ in. iron, except that close to the gage it is better to use brass pipe. If iron pipe is used near the gage, rust and scale may drop into

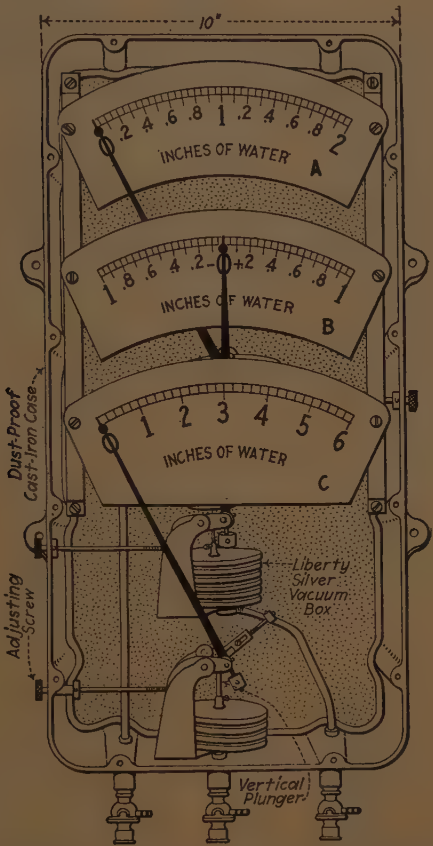


FIG. 393.—Precision Instrument Company's "three-in-one" draft gage with cover removed. (*A* indicates available draft pressure at last pass, *B* that over fuel bed, and *C* that in wind box. Maintain *A* pointer low to minimize chimney-gas loss. Maintain *B* pointer near zero on draft side. If pointer shifts to pressure side, the burning gases will be deflected downward and burn out stoker parts and brick work. Maintain pointer *C* at about 3.5 in. If the fire travel of the boiler is dirty, this cannot be accomplished without forcing *B* to shift to the pressure side. If a hole develops in the fuel bed, needle *C* shifts toward zero.)

the glass. It is often recommended that rubber tubing should not be used for permanent installations. The rubber soon

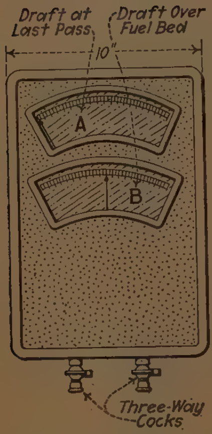


FIG. 394.

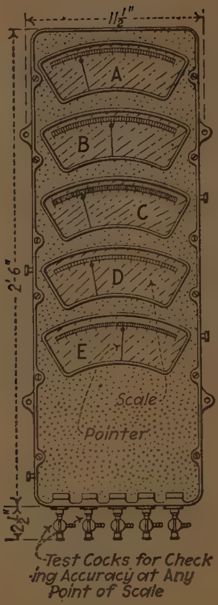


FIG. 395.

FIG. 394.—"Precision" two-in-one draft-pressure gage.

FIG. 395.—Assembly of Precision Instrument Company's "five-in-one" draft gage for use with stoker-fired boilers. (*A* indicates available draft pressure in last pass, *B* that over fuel bed, *C* that at rear compartment of wind box, *D* that at center compartment of wind box and *E* that at front compartment of wind box.)

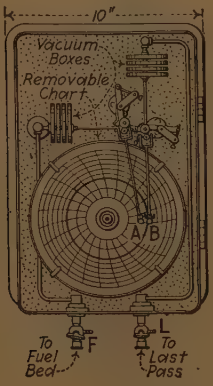


FIG. 396.—Precision Company's graphic draft-pressure gage with cover removed.

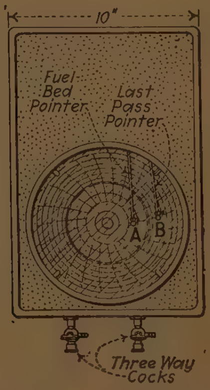


FIG. 397.—Precision Instrument Company's graphic draft-pressure gage assembled.

dries out and cracks under the action of the heat. But, nevertheless, rubber tubing is often so used in exposed places.

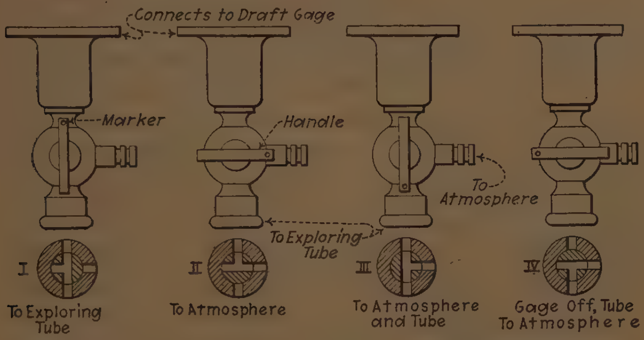


FIG. 398.—Three-way cock used with draft-pressure gages.

The reason is that permanent piping involves a stiff connection. In boiler rooms it often occurs that a poker or bar is accidently placed against draft-gage piping. If the gage is piped rigidly

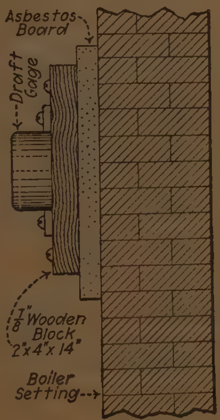


FIG. 399.—Mounting board on boiler front.

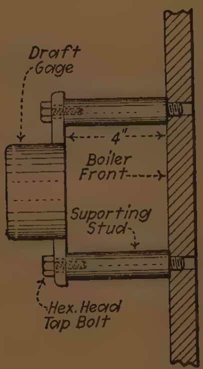


FIG. 400.—Draft-pressure gage mounted on boiler front on studs.

it may receive the shock and be damaged. A rubber tube provides a flexible connection and is readily replaced.

498. In installing draft-pressure gage exploring tubes (Fig. 401), a length of 1 in. iron pipe T, is cemented into the setting. The tee on the outside end provides connection for the pipe to the gages. If it becomes clogged with soot, the plug can be removed and the obstruction padded out.

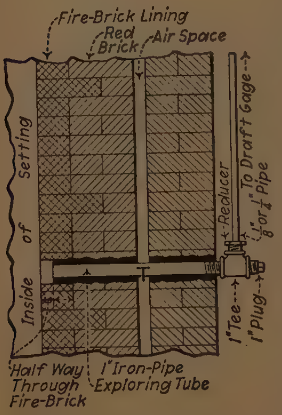


FIG. 401.—Draft-pressure-gage exploring tube installed in setting.

499. The location of exploring tubes in furnaces should be as near as is feasible to the front of the furnace and near the top of the chamber so that slag will not accumulate in it.

500. The best draft-pressure to use in the furnace (U. S. Bureau of Mines Bulletin) is that which will satisfy the load conditions and produce the best percentage of CO_2 without CO and without fusing the ash. There is practically no exception to this rule. Determine the proper draft pressure for your plant by using a CO_2 gas analyzer (an Orsat apparatus).

NOTE.—The best draft pressure over the fire for hand-fired furnaces burning bituminous coal ranges from 0.25 to 0.40 in. water column. But it may be materially more or less depending on the grate used, the size and ash content of fuel and on similiar conditions.

QUESTIONS ON DIVISION 19

1. What is the function of draft in a boiler? Explain.
2. Explain the difference between *draft* and *draft pressure.*
3. Is a boiler draft due to a pressure or to a vacuum?
4. Write a classification of the different methods of producing draft.
5. Explain the functions of a power-plant chimney.
6. Explain, with an example, the basic principle of chimney draft.
7. Explain, using suitable sketches for illustration, how a power-plant chimney produces a draft pressure.
8. In what unit is draft pressure measured in practice? Explain with an example.
9. What is a manometer? Draw a sketch of one and explain how it works and how to read it.
10. Define *total draft pressure.* What produces it? Explain with an example.
11. State the formula for computing the total draft pressure which will be developed by a chimney. What do the symbols mean? Same, for formula for chimney height.
12. What is meant by *drop in draft pressure?* What causes it? Explain in full.

13. Define *available-draft pressure.* How may *available* draft pressure be determined? xplain with a suitable example.

15. State what drops in available-draft pressure may ordinarily be expected through ι) *ash pit*, (*b*) *fuel bed and furnace*, (*c*) *the passes*, (*d*) *in breeching straight runs*, (*e*) *breechιg elbows*, (*f*) *damper*, (*g*) *economizer*, and (*h*) *chimney.*

16. Define *effective draft pressure.* How is it determined?

17. *The sum of the available-draft-pressure drops along the flue gas path from the ash it to the smoke—conduit connection* equals what? Explain with a sketch and an example.

18. State the formula for computing the chimney height required for a given installaion. Explain its derivation.

18a. What factors should determine the flue area for a power-plant chimney? What ccurs if flue area is insufficient?

19. State the formulas for computing the flue area and diameter of a power-plant himney. What do the symbols mean?

20. Explain the steps necessary and the formulas used in proportioning a power-plant himney.

21. What types of draft-pressure gages are used in practice? Explain their operating rinciples.

22. Discuss the locating, installing and piping of draft-pressure gages and exploring ubes.

23. What is the best draft-pressure to use over the fire for maximum economy? What are average values of economical draft pressures? What factors affect these values?

PROBLEMS ON DIVISION 19

1. What total draft pressure will be developed by a power-plant chimney which is 110 ft. high and located at the sea level? The average temperature of the outside air is 65 deg. fahr. and that of the flue gases 550 deg. fahr.

2. How high must a chimney be to develop a total draft pressure of 2 in. water column, if it is located at an altitude where the atmospheric pressure is 13 lb. per sq. in.? The average outside-air temperature is 55 deg. fahr. and that of the flue gases 500 deg. fahr.

3. If, at a certain location in a chimney, the draft pressure due to elevation is 0.47 in. and the friction-and-velocity drop up to that location is 0.09 in., what is the available draft pressure at that location?

4. If the available-draft-pressure drop up to the smoke-conduit connection, in a certain installation, is 0.75 in., what total draft pressure must the chimney develop from the smoke connection up?

5. What should be the area of the flue of a 120 ft. high chimney which supplies draft for a battery of boilers which burns 1.5 tons (2,000 lb. tons) of coal per hour?

6. Proportion a chimney for the following plant: Eight boilers rated at 500 h.p. each. Grate area of each, 83 sq. ft. Fuel is Illinois bituminous of which 4 lb. is required per rated boiler h.p. hour. Proportion stack on basis of a 25 per cent. overload. Unlined steel breeching is 50 ft. long and contains two right-angle turns. Plant is to be located 2,000 ft. above sea level where atmospheric pressure is 13.57 lb. per sq. in. Temperature of outside air averages 60 deg. fahr.; that of flue gases 550 deg. fahr.

DIVISION 20

CHIMNEYS, BREECHINGS, AND DAMPERS

501. A power plant chimney or stack may be defined as a vertical hollow column, through the interior of which pass the smoke and gases from the boiler furnace. See Sec. 474 for functions.

NOTE.—Strictly, the term *chimney* relates specifically to a masonry structure, while *stack* refers to one of metal. In power plant nomenclature these two terms are often used synonymously.

502. The constructional requirements for chimneys are, in general, two: (1) *The proportions of the chimney must be such that it will fulfill satisfactorily its functions for a long period of time.* (2) *The materials which are used must be such that they may be worked and assembled readily and that they will withstand to a reasonable extent the effects of any elements which may act upon them.*

503. A Chimney may be Built Either of Masonry, Steel, or Concrete.—Each of these materials has characteristics which adapt it for certain applications but which may render it unfit for others. Often it is a matter of choice as to the material which should be used. But usually there is a good reason, economic or otherwise, for utilizing a certain material.

504. The Principal Agents Tending to Destroy a Chimney are the Weather (Including the Wind), Heat, and the Gases of Combustion.—The rain, and atmospheric and temperature changes tend to wear away the outside of the chimney. Masonry structures, if properly designed, withstand successfully these destructive elements. Dampness and temperature changes render it difficult to prevent corrosion of a steel stack. If the steel is well protected by a suitable paint, there will be little external corrosion. The interior of the steel stack and the seams may be attacked by certain of the products of combustion. The most important of these is sulphur dioxide

A portion of it is converted to sulphuric acid, which "eats away" the steel.

505. A masonry stack, being thick, is relatively cool on the outside, while hot on the inside due to the hot gases. This has a tendency to expand the interior of the chimney more than the outside, thereby pulling apart the exterior of the wall. This may result ultimately in considerable weakening of the structure. In concrete chimneys it is found that the gases, which always carry moisture, are, in passing up the stack, chilled by the relatively cool wall. The moisture is then condensed on the interior of the wall. It enters the fissures and may attack the reinforcing bars. Eventually the stack might fail. Some of the constituents of the gases are thought to attack concrete and impair its strength.

506. All of these interior destructive tendencies, regardless of the material of the stack, are practically eliminated by a suitable lining which may be of concrete, common brick, or firebrick. When the stack is thus lined, it has to withstand only the wind pressure and the destructive tendencies of the natural elements.

507. The Elevation to which a Chimney Lining should Extend may vary from about One-fifth of the Height to the Total Height of the Structure.—The determining factors are: (1) *The temperature of the gases entering the chimney.* (2) *The material of which it is built.* If the gases are relatively cool, say 300 to 500 deg. Fahr., the lining need not extend to any great height, or there may be none. But if the temperature is very high, say, double that specified above, the lining should be extended correspondingly.

508. In designing masonry chimneys, the procedure should be as follows:

1. *The height and flue area of the chimney should be determined to satisfy the conditions under which the stack is to operate* (Secs. 481, 492.)

2. *The thickness of the walls should be calculated* (Sec. 551).

3. *The weight of the chimney should then be calculated from the volume of the material and its weight per cubic foot.*

4. *The maximum stresses due to dead weight and wind pressure may now be computed for any section. Usually these stresses*

must be determined at the planes where the chimney is weakest, such as bed joints, etc. (Sec. 532).

5. *The maximum stress on the soil under an assumed foundation is then determined* (Sec. 524).

6. *If the above conditions are satisfied, then the stability of the structure should be checked as referred to any horizontal section and to the bottom of the foundation* (Sec. 526).

509. In checking the design of a self-supporting steel stack the following procedure is recommended:

1. *The height and flue area of chimney should be sufficient to insure proper functioning* (Secs. 481, 492).

2. *The thickness of the steel plate should be ample* (Secs. 504, 533) *and the riveting properly done* (Sec. 545).

3. *The maximum stresses due to wind on any weak section should be determined, assuming that failure may be due to buckling* (Sec. 533).

4. *The maximum stress, due to wind, imposed upon the supporting soil under the foundation should be calculated* (Sec. 523).

5. *The stability of the structure should be determined with the stack and foundation considered as a unit* (Sec. 526).

510. Any chimney should have ample height for creating the needed draft pressure and for discharging the waste gases at an elevation that will remove all probability of damage to surrounding property and discomfort to occupants of the neighboring premises. Also, it should have ample flue area for passing effectively the gases generated from whatever fuel may be burned in the plant. The height and area, when based primarily on draft requirements (exceptions may be encountered in a tall office building, where the chimney height is predetermined), will be determined by methods explained in Secs. 481 to 492.

511. The effect of wind pressure on a chimney is nearly always an important factor. It will now be considered in some detail. Wind blowing against a chimney tends to: (1) *Overturn it as an integral unit*, Fig. 402. (2) *Break it at some plane of least resistance*, Fig. 403. (3) *Throw it out of perpendicular by causing an edge or corner of the foundation to fail*, Fig. 404, *or to sink it*, Fig. 405, *into the supporting soil.* To

afeguard against failure due to these tendencies, the chimney tructure must be properly designed, as will hereinafter be xplained.

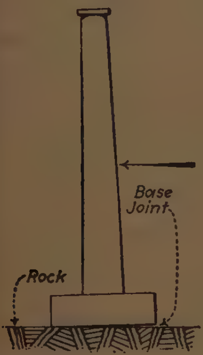


FIG. 402.—Entire structure ilting under wind pressure—nnyielding soil beneath founlation.

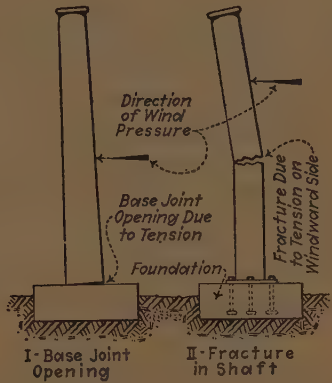


FIG. 403.—Chimney joints opening on windward side due to wind pressure.

512. The maximum wind pressure assumed as acting upon each square foot of projected area of one side of a square

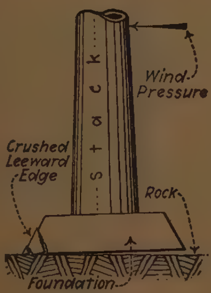


FIG. 404.—A chimney foundation may crush on the edge.

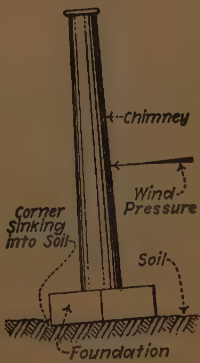


FIG. 405.—Leeward corner of foundation sinking under wind pressure.

chimney is 50 lb. When the chimney is hexagonal, the pressure may be taken as about 40 lb. per sq. ft. of projected area,

when octagonal as between 30 and 35, and when round a
between 24 and 30 lb. per sq. ft. In the determination of th
above values, it was assumed that the most violent wind
never has a velocity exceeding 100 mi. per hr. Such velocitie
have been recorded. Chimneys properly designed on the basi
of the above-stated values will, so experience has shown, stand

513. The computation of the wind pressure acting on a chimney is based on the fact that the pressure, upon a surface due to wind is found to vary approximately as the square of th wind velocity. Thus the following formula is often used fo determining the pressure imposed at different velocities.

(75) $$P = kv^2$$ (pressure, pounds per square foot

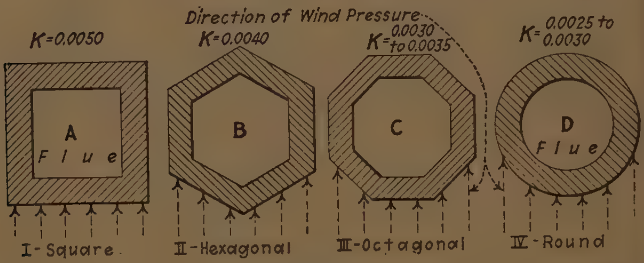


Fig. 406.—Values of the wind-pressure constant k, for chimneys of differen sections.

Wherein P = the pressure due to wind upon a square foot o projected area, in pounds. k = a constant determined by th contour of the surface against which the wind is blowing. = the velocity of the wind in miles per hour. On the basis o the unit pressures stated in the preceding section, the values o k which may be safely used (Fig. 406) are: Square chimney 0.005. Hexagonal chimneys, 0.004. Octagonal chimney 0.003 to 0.0035. Round chimneys, 0.0025 to 0.003.

Note.—The values of k as computed from data presented by variou authorities, vary, for example: Parsons,—square, 0.005; octagona 0.00375; round, 0.0025. Peabody and Miller,—square, 0.0055; hexa onal, 0.0041; octagonal, 0.0038; round, 0.003. Rankine—(assuming value of 0.005 for square chimney) hexagonal, 0.00375, octagonal, 0.00 round, 0.0025. Henry Adams—(assuming a value of 0.005 for squa chimney) octagonal, 0.0041; round, 0.0039. Pratt—square, 0.00 octagonal, 0.0035; round, 0.0025. All the quoted values are high,

has been shown that, except upon small surfaces, the value of k for a 00-mile-per-hour wind is only about 0.0032 (Gebhardt) which corre-ponds to a value of 32 lb. per sq. ft. for a wind velocity of 100 mi. per hr.

EXAMPLE.—A storm wind blowing 75 mi. per hr. impinges squarely against a steel stack (Fig. 407-I). What pressure per square foot of pro-ected area (Fig. 406-IV) does the stack sustain? SOLUTION.—By ormula: $P = kv^2 = 0.0025 \times 75^2 = 14.06$ *lb. per sq. ft.* of projected rea.

514. Most chimneys, particularly those of masonry, have a aper, or batter, because the wall thickness may be decreased oward the top without decreasing materially the stability or

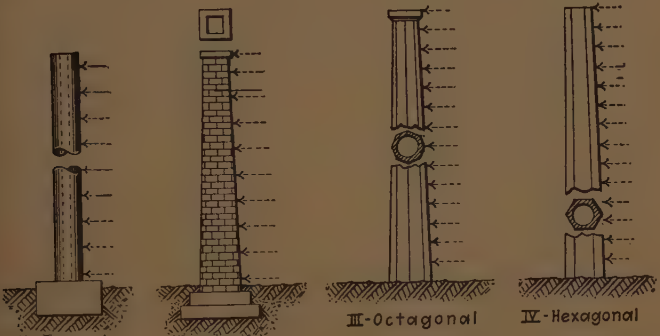


FIG. 407.—Four examples in computing wind pressure against chimneys.

strength of the structure. The tapered surface is always on the outside. Hence, the flue remains of constant diameter from bottom to top. When the stack is tapered, less material is needed. Furthermore, the total force of wind pressure is diminished, since the projected area of the upper portion is smaller than with a straight stack. The taper (Figs. 408 and 409) for the side of a chimney may be approximately 3⁄16 or ¼ in. to the foot.

515. To compute the total wind pressure against the whole or any section of a tapered chimney, the following formula may be used:

(76) $$F = \frac{L_{wb} + L_{wt}}{2} L_h P \qquad \text{(force, pounds)}$$

Wherein F = total pressure due to wind, in pounds. L_{wb} = width of base of chimney, or of section thereof, in feet. L_{wt}

= width of top of chimney, or section thereof, in feet. L_h = height of chimney, or section thereof, in feet. P = assumed pressure due to wind, in pounds per square foot, as computed from For. 75. When the chimney is partially shielded by adjacent buildings (Fig. 411), only that portion need be considered which is actually exposed to the wind.

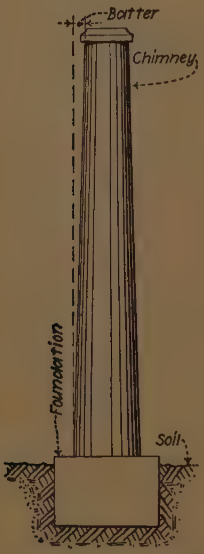


FIG. 408.—Masonry or concrete chimney with uniform batter.

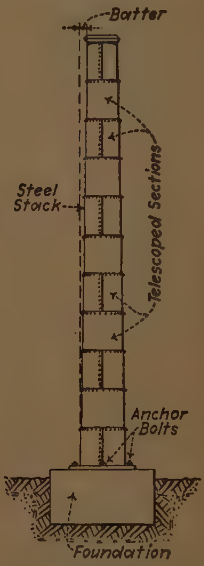


FIG. 409.—Battered steel chimney.

516. The total force of the wind may be assumed to act at the center of gravity of the projected exposed area of a chimney when determining the effect of the wind pressure upon the stability of or upon the stresses in the structure. This point at which the force of the wind may be assumed to act is called the *center of wind pressure*.

NOTE.—THE CENTER OF GRAVITY of an object is that point within the object at which the weight of the object may be assumed to act. The center of gravity of a plane surface is the point at which the total force due to a uniformly distributed force, may be considered as being applied. If a thin sheet of material be suspended at its center of gravity, it will

-hen have no tendency to rotate from any position in which it may be -laced.

EXAMPLE.—From Fig. 410, the total wind pressure, when the wind is exerting a pressure of 14 lb. per sq. ft. = 50 × 10 × 14 = 7,000 *lb.* which may be considered as being applied as a single concentrated force, *F*, at the center of gravity, *G*, of the projected area.

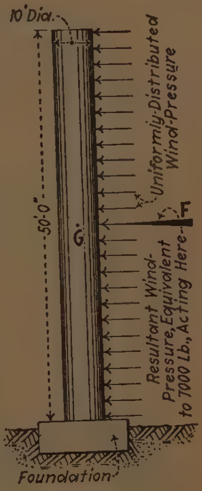


FIG. 410.—Illustrating concentration of wind pressure at center of gravity of projected area.

517. To compute the height of the center of gravity of the projected area of a uniformly tapered chimney, or of any section of it, the following formula may be used:

$$L_{hc} = \frac{L_{wb} + 2L_{wt}}{L_{wb} + L_{wt}} \times \frac{L_h}{3} \quad \text{(feet)} \tag{77}$$

Wherein L_{hc} = height of the center of gravity of the projected area of the chimney or section of it, in feet. L_h = total height of the chimney or section, in feet. L_{wb} = width of the bottom of the chimney or section, in feet. L_{wt} = width of the top of the chimney or section, in feet.

EXAMPLE.—What is the height of the center of wind pressure above the base of the wind-exposed section of a chimney (Fig. 411) which extends 72 ft. above the lowest of several buildings which surround it? Its top is 6 ft. across and the base of the section is 8 ft. SOLUTION.—Substituting in the above formula: $L_{hc} = [(L_{wb} + 2L_{wt}) \div (L_{wb} + L_{wt})] \times (L_h \div 3) = \{[8 + (2 \times 6)] \div (8 + 6)\} \times (72 \div 3) = 34.3$ ft.

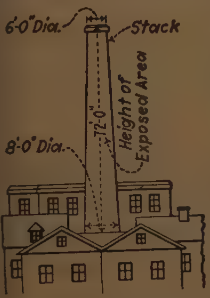


FIG. 411.—Chimney partially shielded from wind by surrounding buildings.

NOTE.—In practice it is often assumed that the center of wind pressure is at one-half the height of the chinney or exposed section. Since the velocity, and hence the wind pressure, is greater at the top of the chimney than at the bottom, there is very little error in using this method. Such error as there may be is on the safe side.

NOTE.—THE CENTER OF GRAVITY OF THE PROJECTED AREA OF A WIND-EXPOSED CHIMNEY MAY BE FOUND CONVENIENTLY BY AN EXPERIMENTAL METHOD (Figs. 412 and 413). A scale drawing of the complete chimney structure is cut from cardboard. The model thus made is pierced near opposite corners *a* and *b*. The

model is first suspended from a pin passed through a (Fig. 412) and a plumb made of fine thread and suitable weight is likewise suspended from the same pin. The point, p, where the plumbline intersects the edge of the model is marked.

The model is then suspended from b (Fig. 413) and the point p_1 is similarly marked. The intersection, c, of the lines ap and bp_1 locates the center of gravity of the area. If the model is perfectly free to

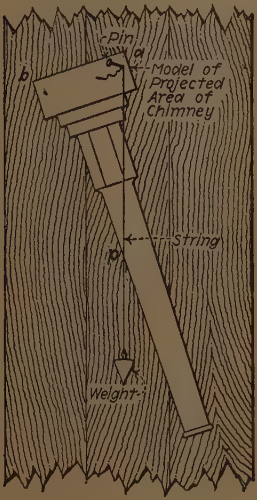


FIG. 412.—Experimental method of finding center of gravity.

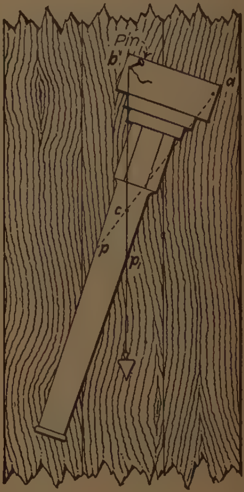


FIG. 413.—Experimental method of finding center of gravity.

oscillate about the points of suspension, and is kept clear of any object that might retard its free motion, it will always come to rest with its center of gravity precisely in the respective vertical lines (plumb lines) passing through the points of suspension.

518. The sustaining ability of the soils on which chimney foundations bear must be considered in the design of any important structure. Practice and experiment have shown that there are certain safe pressures which should not be exceeded. After the weight of a proposed chimney and foundation has been computed, then the weight per square foot which it will impose on the supporting soil should be calculated. If the weight so imposed will be excessive, then the bearing area of the foundation must be made larger so that it will extend over more earth area and thereby decrease the weight imposed per

square foot. The following table quotes unit pressures which practice has shown to be safe.

519. Table giving allowable foundation pressures on soils (Baker's Treatise on Masonry Construction, p. 342.)

Kind of material	Safe bearing power			
	Tons per sq. ft.		Lb. per sq. in.	
	Min.	Max.	Min.	Max.
Rock—the hardest—in thick layers in native bed	200	..	2.778	..
Rock, equal to the best ashlar masonry	25	30	347	416
Rock, equal to the best brick masonry	15	20	208	278
Rock, equal to poor brick masonry	5	10	69	139
Clay, in thick beds, always dry	6	8	83	111
Clay, in thick beds, moderately dry	4	6	56	83
Clay, soft	1	2	14	28
Gravel and coarse sand, well cemented	8	10	111	139
Sand, dry, compact and well cemented	4	6	56	83
Sand, clean, dry	2	4	28	56
Quicksand, alluvial soils, etc.	0.5	1	7	14

NOTE.—Use the minimum values rather than the maximum. The building laws of a locality may specify the safe values which must be assumed in that locality. If so, such values should be used.

520. On Uncertain Soils the Chimney Foundation Should be Supported on Piles.—The piles should, preferably, be driven to bed rock. A sandy, loose soil usually requires piles. Christie in his CHIMNEY DESIGN, p. 34, states that piles should be of spruce with a diameter not less than 6 in. and driven by a drop hammer weighing one ton or more. The upper ends of the piles are then covered with a concrete footing and the foundation is built thereon. Wooden piles should not be closer together than 2½ to 3 ft. Each wooden

pile may be expected to support a load of from 8 to 12 tons. Concrete piles may be designed to bear an average of about 30 tons each. (Marks, MECHANICAL ENGINEERS' HANDBOOK, p. 1265.) The concrete pile is indestructible and may be driven after molding and seasoning. Or, it may be molded in place in a mandrel which has been driven into the ground.

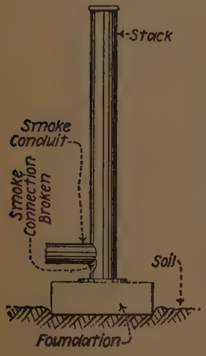


FIG. 414.—Settling of foundation into underlying soil.

521. The Bearing Area of any Chimney Foundation must be Sufficiently Great to prevent Uniform Settling.—If the pressure per square foot imposed by the dead weight of the stack and its foundation exceeds the values specified in Table 519, the structure is likely to sink vertically into the supporting soil. This may result in straining and deranging the smoke connection between the boiler and chimney (Fig. 414) or in other damage. When a stack will never be exposed to wind pressure, the bearing area may be determined by applying this doctrine. That is:

$$(78) \qquad A = \frac{W_t}{p'_c} \qquad \text{(area, square feet)}$$

Wherein A = bearing area of foundation, in square feet. W_t = weight of the stack and foundation, in tons. p'_c = pressure imposed by dead weight of stack and foundation, in tons per square foot = allowable bearing pressure on soil, in tons per square foot, from Table 519.

NOTE.—When wind impinges against a stack, the result is to increase the pressure under the leeward side of the stack foundation. Then, the tendency is for the extreme leeward edge to sink (Fig. 405) into the supporting soil. When a stack is to be thus exposed to wind, the foundation area must be so proportioned and distributed that it will safely support the total load due to the dead weight and also that due to wind. Hence, a wind-exposed stack must be designed accordingly. How the maximum load, due to the combined dead weight and wind, can be computed will be shown in a following Sec.

EXAMPLE.—If a certain chimney and its foundation weighs 85 tons and bear on a soil which will safely support 2 tons per sq. ft., what must be the area of the bearing surface of the foundation? Disregard

effects of wind pressure. SOLUTION.—Substituting in formula: $A = W_t/p'_c = 85 \div 2 = 42.5$ *sq. ft.* which is the area required.

522. When Wind Impinges on a Stack, the Stack Acts like a Lever Arm and Tends to Force the Leeward Edge of the Foundation into the Soil (Fig. 415).—It is assumed that the chimney, in shifting, rotates about some point, O. (The location of this point need not necessarily be under the center of the foundation as is shown in the illustration.) The bearing strength of the soil under the leeward side tends to prevent this tipping. But if the bearing strength of the soil under the leeward edge is exceeded, the stack will, obviously, tilt.

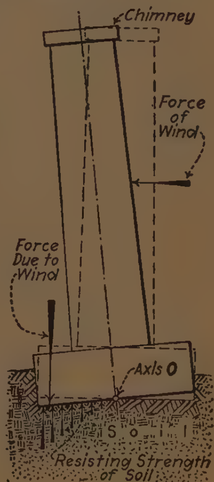


FIG. 415.—Wind pressure is converted to a downward force.

523. The formula for computing the maximum pressure, due to wind alone, under the extreme leeward edge of the foundation is as follows:

(79) $$p''_c = \frac{FL_{hc}}{\frac{I}{c}}$$ (pressure, pounds per square inch)

Wherein p''_c = maximum compressive stress in pounds per square inch due to wind pressure. F = force in pounds due to wind considered as applied at the center of wind pressure. L_{hc} = height of center of wind pressure above the base, in inches. I/c = section modulus of the supporting area of the foundation. Values of I/c for various areas may be found in handbooks.

EXAMPLE.—A total wind pressure of 10,000 lb. is considered as applied at 50 ft. above the bottom of a round foundation. What will be the maximum compression due to the wind only, when the base is 16 ft. in diameter? SOLUTION.—The value of I/c for a circle is $0.1d^3$ approximately. Then, substituting in the formula: $p''_c = FL_{hc} \div I/c = (FL_{hc}) \div (0.1d^3) = 10{,}000 \times (50 \times 12) \div 0.1(16 \times 12)^3 = 8.48$ *lb. per sq. in.*, or 0.61 *tons per sq. ft.*, which is the pressure under the leeward edge. At every other point under the foundation the pressure is less than 0.61 tons per sq. ft.

524. The total maximum unit pressure imposed upon the supporting earth is found by adding that due to dead weight and that due to wind, thus:

$$(80) \qquad p_c = p'_c + p''_c \qquad \text{(pressure, pounds per square inch)}$$

Wherein p_c = total maximum pressure in pounds per square inch. p'_c = pressure, in pounds per square inch, due to dead weight of chimney and foundation. p''_c = maximum pressure on extreme leeward edge, in pounds per square inch (Formula 79).

525. The Wind may Overturn a Chimney if its weight and Supporting Foundation Area are not Properly Proportioned (Fig. 402).—In practice, the materials used in the foundation and the nature of the supporting soil are such that when failure occurs it will be due either to (1) *Yielding of the soil under the foundation* (Fig. 415). (2) *Crushing of the extreme leeward edge of the foundation* (Fig. 404). Obviously, the chimney will topple over more readily when such failure as this occurs.

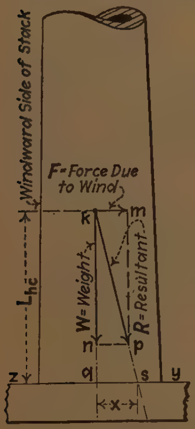


FIG. 416.—Graphic method of determining stability.

NOTE.—When designing a chimney, even if the computations show that the allowable stress upon the chimney material will not be exceeded and that the maximum stress on the supporting soil will be within the allowable limit, the structure should be checked for stability in accordance with rules given in following Secs.

526. The stability of a chimney, or of a portion of it above any plane, i.e., its tendency to remain upright, may be determined by a graphical method by employing the principle of the *composition of forces*. This involves the finding of one force which is equivalent in direction and magnitude to all the forces under consideration.

EXAMPLE.—It is desired to determine graphically the stability of a chimney. Refer to Fig. 416, in which the chimney is drawn to some certain scale, say, 1 in. = 1 ft. Then center of wind pressure is located at k. The distance kn is drawn so as to be proportional in length to the weight in pounds of the chimney or of the portion of it above any certain

plane, for example *zy*. The maximum wind pressure in pounds is indicated to scale by the length *km*. The parallelogram *knpmk* is then completed and the diagonal *kp* drawn. The length of *kp* is then proportional to and gives the direction of the resultant force, *R*. By extending the line of the resultant to the base of the portion of chimney under consideration, the position *s* on *zy* is located. If *s* falls within a certain distance, x, from the vertical axis, q, (as will be explained later) the chimney is safe or "stable." If x is greater than the radius of the base, then the chimney has, when subjected to the wind pressure, a tendency to turn over regardless of material. If s is near the edge of the chimney, the leeward side may be crushed and the windward side pulled apart in the tension when the wind blows against the stack.

527. The distance from the axis of the chimney base to the point where the resultant cuts the base may be found from the proportion (Fig. 416).

(81) $$\frac{x}{F} = \frac{L_{hc}}{\mathrm{W}}$$

from which the following formula is derived:

(82) $$x = F\frac{L_{hc}}{\mathrm{W}} \qquad \text{(distance, feet)}$$

Wherein x = distance, in feet, from the vertical axis, q, of the section of the chimney to the point, s, where the resultant pierces the section. See the following Sec. for the allowable value of x. F = force due to the wind pressure, above the plane zy, in pounds. L_{hc} = distance from the section zy to the center of pressure, k, of the wind, in feet. W = weight of the chimney above the section zy in pounds.

Note.—The above formula follows from the fact that triangle *knp* is similar to triangle *kqs*, and $L_{hc} = qk$, $W = nk$, $x = qs$, $np = km = F$. Therefore, since

(83) $$\frac{qs}{np} = \frac{kq}{kn}$$

then

(84) $$\frac{x}{F} = \frac{L_{hc}}{\mathrm{W}}$$

528. The allowable maximum value for x, or the maximum distance from the axis of the base section of the chimney to the point where the resultant of the wind pressure and the weight of the chimney above the section passes, may be

found mathematically, but the following rule is often used: *The resultant should pass not further from the axis of the chimney section than ½ the outer radius plus ¼ the inner radius. For other than round chimneys use the radii of the inscribed circles* (Parsons in "STEAM BOILERS"). *This rule applies to any section of masonry stacks where no tension can be allowed in the outer edge of the wall.*

NOTE.—For self-supporting chimneys, supported on a square foundation, the resultant should pass through the lower surface of the foundation not further from the axis than ⅙ the side of the foundation.

NOTE.—Calculations for concrete stacks, in which tension is always allowable on the windward side, become complicated due to the combined steel-and-concrete construction. Hence, expert reinforced-concrete-stack designers should be consulted concerning concrete stack design.

529. The Thickness of a Chimney Wall Should be so Proportioned as to Provide a Sufficient Margin of Strength against Crushing, Buckling, and Tension.—This applies to any horizontal cross-section from the base upward (Figs. 406 and 407). When wind need not be considered, the stresses set up in the chimney structure are due only to its weight. Hence, they are compressive. The essential formulas are given below.

530. The formula for computing the unit stress due to the weight of any chimney above a certain section is:

$$(85) \qquad P'_c = \frac{W}{.7854(d_o^2 - d_i^2)} \quad \text{(stress, lb. per sq. in.)}$$

Wherein: P'_c = compressive stress due to the weight of the material above the section in consideration, in pounds per square inch. W = weight of the structure above the section, in pounds. d_o = outside diameter of chimney at the section, in inches. d_i = inside diameter of chimney at the section, in inches. The expression $0.7854\ (d_o^2 - d_i^2)$ gives the area of this section.

531. The theoretical formula for Computing the unit stress induced at any horizontal chimney section by wind pressure is derived by considering the chimney to act as a cantilever beam. When wind blows against a chimney there

is a compressive stress set up in the leeward side and a tensile stress is set up in the windward side. The formula is

$$(86) \qquad P''_c = \frac{FL_{hc}}{\frac{I}{c}} \qquad \text{(stress, pounds per square inch)}$$

Wherein: P''_c = maximum stress, either tension or compression, due to wind, at the section under consideration, in pounds per square inch. F = force due to wind considered as applied at the center of pressure, in pounds. L_{hc} = height of the center of wind pressure (Formula 77) above the section of the structure, in inches. I/c= section modulus of the section (the value may be found in handbooks.) The maximum stress occurs only in the extreme leeward or windward fibers, or grains, of the chimney.

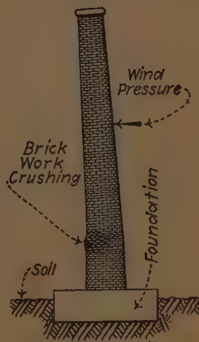


FIG. 417.—Insecure brickwork failing under weight of superstructure and wind pressure.

532. To compute the net compressive or tensile stress in any section due to both weight and wind pressure, the same principle is used as that adopted for computing pressure under the foundation (Sec. 524). It is necessary to know if the compressive stress, due to both wind and weight combined, on the leeward side of the structure is excessive for the material Fig. 417. This is found by adding P'_c and P''_c. On the windward side the wind has a tendency to produce tension while the weight causes compression. The net result may be either tension or compression. That is, if P'_c is greater than P''_c, then the net stress is compressive and equals $P'_c - P''_c$. If P''_c is greater than P'_c, the net stress is tensile and equals $P''_c - P'_c$.

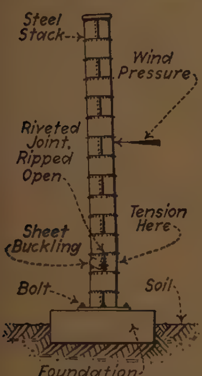


FIG. 418.—Thin ring course failing under weight and wind pressure.

533. When a Chimney is Built of Thin Material (such as Steel) and is Circular in Section, it will fail by Flattening or Buckling rather than by Crushing or

Pulling Apart.—See Fig. 418. In computing the stress imposed on the plates of steel stacks the weight is neglected. Then, the simplified formula used by steel stack manufacturers is:

$$(87)\qquad P'''_c = \frac{FL_{hc}}{.8d_o^2L_t}\quad \text{(stress, pounds per square inch)}$$

wherein P'''_c = stress in pounds per square inch. L_t = thickness of steel plate in inches. Other symbols have same meanings as stated above. The safe stress shown in Table 534 should not be exceeded.

534. Table.—The Safe Stresses for the Various Materials Used in Chimney Construction.

Material		Safe stress	
		Pounds per sq. in.	Tons per sq. ft.
Brickwork in Portland cement		208–250	15–18
Brickwork in lime and cement		140–170	10–12
Brickwork in lime		110	8
Radial brick in lime and cement		278	20
Hollow tile		60–80	4.3–5.8
Firebrick	In fireclay	110	8
Firebrick	In air drying or firing cement	170	12
Concrete		208–350	15–25
Steel, single riveted		8,000	576
Steel, double riveted		1,0000	720
Steel, no rivets		15,000	1,080

535. The weights of material used in building masonry chimneys are about as follows: Brick masonry, 120 lb. per cu. ft., Concrete, 150 lb. per cu. ft., Steel, 489 lb. per cu. ft.

Example.—The brick chimney shown in Fig. 419 weighs about 430,000 lb. What is the unit compressive stress due to weight alone at the bottom, *MN*? Solution.—The stress may be determined by substituting in Formula 85, thus: $P'_c = W/[0.7854(d_o^2 - d_i^2) = 430{,}000 \div [0.7854 (96^2 - 54^2)] = 87$ *lb. per sq. in.*

Example.—Find the stress due to wind alone in the outer part of the

chimney wall, at P and Q, Fig. 419, due to a wind pressure of 17 lb. per sq. ft. of projected area when assumed as applied at a height of 45 ft. above the top of the foundation. SOLUTION.—Total force, F = *projected area* × *wind pressure* = $[(8 + 7) \div 2] \times 96 \times 17 = 12{,}240$ *lb.* By Formula 86: $P_c'' = FL_{hc}/(I \div c) = (FL_{hc})/\{0.7854[(r_o^4 - r_i^4) \div r_o]\}$ $= [12,\ 240 \times (45 \times 12)] \div \{0.7854[(48^4 - 27^4) \div 48]\} = 84.5$ *lb. per sq. in.* tension at P and compression at Q.

EXAMPLE.—What are the maximum imposed stresses due to weight and wind in the chimney column of Fig. 419 when the wind is blowing? SOLUTION.—On the leeward side the total pressure, $P_c = P'_c + P''_c = 87 + 84.5 = 171.5$ *lb. per sq. in.* On the windward side the stress is the difference between P'_c and P''_c, or $P_c = P'_c - P''_c = 87 - 84.5 = 2.5$ *lb. per sq. in.* Since P'_c on the windward side is compression, then net stress, 2.5 *lb. per sq. in.*, is compression. The chimney is safe if the wind pressure is never great enough to change the stress on the windward side to tension.

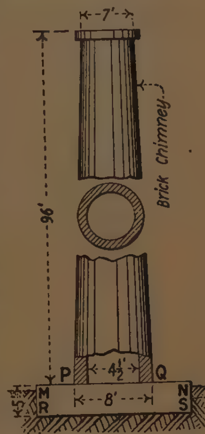


FIG. 419.—Example in chimney design.

EXAMPLE.—Assuming the foundation ($MNRS$, Fig. 419) to be of concrete, 5 ft. deep, and octagonal, 12 ft. across flats, what will be the maximum unit pressure on the earth due to weight and wind? SOLUTION.—From preceding example, W = 430,000 lb. To find the weight of foundation, multiply the volume by the unit weight. The volume of octagonal prism is V = height × $3.314r^2 = 5 \times 3.314 \times 6^2 = 596.5$ *cu. ft.* If concrete weighs 150 lb. per cu. ft., the weight of foundation, $W_1 = 150 \times 596.5 = 89{,}475$ *lb.* The total weight of chimney and foundation $W_2 = W + W_1 = 430{,}000 + 89{,}475 = 519{,}475$ *lb.* The stress per square inch due to weight, $p'_c = W_2 \div A = 519{,}475 \div (3.314 \times 72^2) = 30.2$ *lb. per sq. in.* The stress due to wind $= p''_c = (FL_{hc})/(I \div c)$, in which I/c for an octagon $= 0.109d^3$. Therefore $p''_c = [12{,}240 \times (50 \times 12)] \div (0.109 \times 144^3) = 22.6$ *lb. per sq. in.* The total compressive stress on leeward side, $p_c = p'_c + p''_c = 30.2 + 22.6 = 52.8$ *lb. per sq. in.* or 3.81 *tons per sq. ft.*, which is safe (Table 519) for clay. It is to be noted that the stress due to weight is greater than that due to wind, hence there is compression on the windward side, $p_c = p'_c - p''_c = 30.2 - 22.6 = 7.6$ *lb. per sq. in.*

EXAMPLE.—What is the maximum stress on the ground when the foundation (Fig. 419) is circular and 12 ft. in diameter? SOLUTION.—The volume, $V = 5 \times (0.7854d^2) = 565.5$ *cu. ft.* Weight of base, $W_1 = 150 \times 565.5 = 84{,}825$ *lb.* Total weight of chimney and foundation, $W_2 = W + W_1 = 430{,}000 + 84{,}825 = 514{,}825$ *lb.* Stress due to weight, $p'_c = W_2 \div A = 514{,}825 \div (0.7854 \times 144^2) = 31.5$ *lb. per sq. in.* Since for a circle, $I/c = 0.1d^3$, the stress due to wind, $p''_c = (FL_{hc})/(I \div c)$

$= (FL_{hc})/(0.1d^3) = [12{,}240 \times (50 \times 12)] \div (0.1 \times 144^3) = 24.6$ *lb. per sq. in.* Maximum stress on ground under leeward edge $= p_c = p'_c + p''_c = 31.5 + 24.6 = 56.1$ *lb. per sq. in.* or 4.0 *tons per sq. ft.*, which is safe (Table 519) on good clay.

EXAMPLE.—If the foundation (Fig. 419) is 12 ft. square, what will be the stress on the ground? SOLUTION.—Volume of foundation $V = 12^2 \times 5 = 720$ *cu. ft.* Weight, $W_1 = 150 \times 720 = 108{,}000$ *lb.* Total weight of chimney and foundation $= W_2 = W + W_1 = 430{,}000 + 108{,}000 = 538{,}000$ *lb.* Stress due to weight, $p'_c = W_2/A = 538{,}000 \div 144^2 = 25.9$ *lb. per sq. in.* Stress under leeward edge, when $I/c = 0.118d^3$, $p''_c = (FL_{hc})/(0.118d^3) = [12{,}240 \times (50 \times 12)] \div (0.118 \times 144^3) = 20.8$ *lb. per sq. in* Maximum stress, $p_c = p'_c + p''_c = 25.9 + 20.8 = 46.7$ *lb. per sq. in.* or 3.36 *tons per sq. ft.*

EXAMPLE.—A steel single-riveted stack is 5 ft. in diameter, 125 ft. high, made of plate 5/16 in. thick and withstands a wind which exerts a pressure of 40 lb. per sq. ft. against a flat surface. Taking into account only wind pressure, what is the maximum stress set up in the steel? SOLUTION. As wind pressure against a round surface is assumed as ½ that against a flat surface, the effective pressure is 20 lb. per sq. ft. Total force due to wind $= F = area \times pressure = (5 \times 125) \times 20 = 12{,}500$ lb. If the center of wind pressure is 62½ ft. from the base (Sec. 517), $P'''_c = FL_{hc}/0.8d_0^2L_t = [12{,}500 \times (62.5 \times 12)] \div [0.8\,(5 \times 12)^2 \times 5/16] = 10{,}416$ *lb. per sq. in.*, which is too high, as only about 8000 *lb. per sq. in.* (Table 534) is allowed for single riveted stacks. If the thickness of plate is increased to 7/16 in. the stress decreases to 7,440 *lb. per sq. in.*

EXAMPLE.—If the steel plate in the above example has a uniform thickness to the top, what will be the additional stress due to weight? SOLUTION.—It is found that the steel plate necessary to make the stack has a volume of 50.8 cu. ft., which weighs about 25,000 lb. A pressure of about 427 *lb. per sq. in.* is added. This stress is so small that it is usually neglected.

EXAMPLE.—If the steel chimney of the preceding example be placed on a foundation 7 ft. deep and 16 ft. square, which rests on sand in its natural bed, will it be safe as a self-supporting structure? SOLUTION. The weight, $W = 25{,}000$ *lb.* Weight of base, $W_1 = 16^2 \times 7 \times 150 = 268{,}800$ *lb.* The stress on the sand due to weight alone of the chimney and foundation $p_c' = W_2/A = (W + W_1)/A = (25{,}000 + 268{,}800) \div (12 \times 16)^2 = 7.98$ *lb. per sq. in.* The stress on the sand, due to wind; $p_c'' = (FL_{hc})/(I \div c) = (FL_{hc}) \div (0.118d^3) = \{12{,}500\,[(62.5 + 7) \times 12]\} \div [0.118 \times (16 \times 12)^3] = 12.47$ *lb. per sq. in.* The maximum stress on the leeward side, $p_c = p_c' + p_c'' = 7.98 + 12.47 = 20.45$ *lb. per sq. in.* or about 1.47 *tons per sq. ft.*, which is safe (Table 519). On the windward side, $p_c'' - p_c' = 12.47 - 7.98 = 4.49$ *lb. per sq. in. tension*, since p_c'' is greater. If the stack is lined with firebrick the stress will be increased slightly and the tension on the windward side may be eliminated.

536. The Earth will give away Under a Square Foundation when the Wind is Blowing Diagonally Across it Rather than when Blowing Perpendicularly Against One Side.—This is illustrated by the following example.

EXAMPLE.—A certain round chimney has a center of wind pressure 60 ft. above the bottom of its foundation and a force of 14,000 lb. is exerted by the wind. If the base is 15 ft. square, what will be the difference in the maximum stresses when the wind blows diagonally across the foundation and when it blows perpendicular to one side? SOLUTION.—When a square rotates about a center line parallel to a side (Fig. 420), $I/c = d^3/6$. When it rotates about a diagonal (Fig. 420), $I/c = 0.118d^3$. Therefore, for wind blowing perpendicular to one side:

$p_c'' = (FL_{hc})/(I \div c) = (FL_{hc})/(d^3 \div 6) = [(14{,}000 \times (60 \times 12)] \div [(15 \times 12)^3 \div 6] = 10.3$ *lb. per sq. in.*

For wind blowing diagonally or against a corner:

$p_c'' = (FL_{hc})/(I \div c) = (FL_{hc})/(0.118d^3) = [14{,}000 \times (60 \times 12)] \div [(15 \times 12)^3 \times 0.118] = 14.6$ *lb. per sq. in.* These values show that the greater (possibly excessive) stress occurs when the wind blows diagonally.

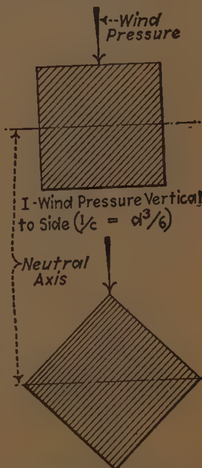


FIG. 420.—Illustrating values for I/c for a square.

537. A steel chimney may often be built inside the boiler house midway of the battery of boilers which it serves. This is feasible, due to the small outside diameter of a steel stack as compared with a masonry stack. Building the stack in the boiler room is an advantage inasmuch as it minimizes the length of the smoke conduit. This insures maximum draft and reduces installation expense. Further space saving may be effected by mounting the stack on the breeching, but this should not be done when it can be avoided.

538. Steel chimneys, or stacks, may be classified according to the method of supporting them, *i.e.*: (1) *Guyed stacks*, or those which are held upright by guys only (Fig. 421). (2) *Semi-self-sustaining stacks*, or those which are held upright partially by the foundation and partially by guys (Fig. 422). (3) *Self-sustaining stacks* or those wholly supported by the foundation (Fig. 423).

539. A Chimney which is not Self-sustaining must be Braced or Guyed.—This is necessary: (1) *When the stack is steel and supported on the breeching* (Fig. 421). (2) *When the stack is too tall to be self-supporting by anchoring with anchor bolts at the bottom to its foundation.* (3) *When it is not feasible to provide a base or foundation sufficiently large to support the stack against overturning.*

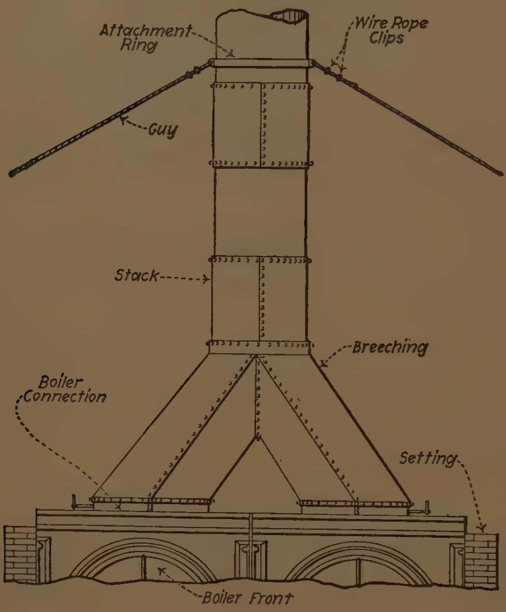


Fig. 421.—Guyed stack mounted on breeching.

540. If the Stack is Set upon a Separate Foundation, Usually One Set of Guy Ropes will be Sufficient.—But when a stack is supported by the breaching (Fig. 421) a very unstable structure results and it should have more staying usually two sets of guys having three or four ropes in each set. Steel ropes are used for guys.

Note.—Where one set of guys is provided they should be attached at a location about 2/3 the height of the stack from its base. Where there are two sets, one is attached at about 2/5 the height and the other at about 4/5 the height. Where there are three sets they are attached at about 3/7, 4/7 and 6/7 the height.

541. The Guy Ropes should be Attached to Guy Bands which are Riveted to the Stack as Shown in Fig. 424.—Other means of fastening are used but the band is preferable because it affords a strong, economical construction.

542. To determine the size Guy rope to use for a stack, the following approximate procedure may be followed. Exact rational methods are impossible. Assume that the force due to the wind is supported by only one guy in each set and by the foundation, if it is suitable. That is, if there is one set, assume one guy and the foundation take all the horizontal force imposed on the stack. If there are two sets assume that one guy from each set and the foundation resist the force. Compute the horizontal force imposed on each guy as follows: For the top guy, the load will be the force of the wind pressure (Fig. 425) against all of the projected area above the point of attachment plus that against 6/10 the projected area between the point of attachment of the top guy and the next lower guy, or the top of the foundation in case there is only one set of guys.

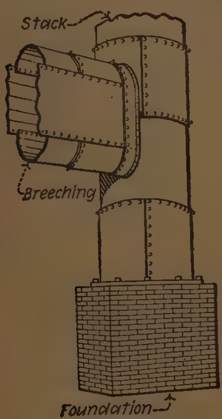


FIG. 422.—Stack with brick foundation.

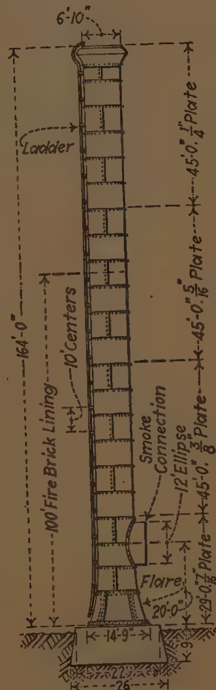


FIG. 423.—Typical example of self-supporting steel chimney.

For other than the top guy, where there are more than one set, take $\frac{6}{10}$ the projected area between it and supports or guy wire attachments above and below. This $\frac{6}{10}$ instead of $\frac{1}{2}$ is assumed to partially correct for irregular initial tension and other indeterminate stresses. Some designers use a value of 0.7 instead of 0.6. Divide the horizontal force, as above computed, by the sine of the angle (Fig. 425) between the stack and guy. This gives the tension in the guy. To allow for initial tension, add 2,500 to 5,000 lb. for guys from $\frac{1}{2}$ to $\frac{7}{8}$ in. in diameter.

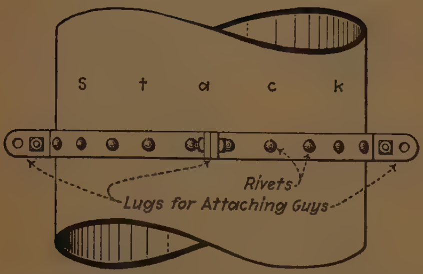


FIG. 424.—Guy band riveted to steel stack.

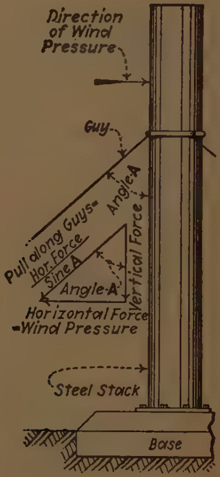


FIG. 425.—Computing tension in guy rope.

EXAMPLE.—A steel stack is 150 ft. high and 4 ft. in diameter. It is guyed at 100 ft. from the ground. If the guy slopes 45° from the chimney, what stress must be taken by the guy when the wind pressure is 25 lb. per sq. ft.?

SOLUTION.—Length of projected area is distance above guy attachment + $\frac{6}{10}$ distance between guy and foundation or 50 + 60 = 110 *ft. Projected area* = 4 × 110 = 440 *sq. ft. Horizontal force* = 25 × 440 = 11,000 *lb. Pull along guy* (Fig. 425) = *horizontal force* ÷ *sine A* = 11,000 ÷ sin 45° = 11,000 ÷ 0.707 = 15,500 *lb.* or about $7\frac{3}{4}$ *tons.* From Table 543 a $\frac{3}{4}$ in. rope is required. But since initial tension must be considered as being about 5,000 lb., or $2\frac{1}{2}$ tons, this should be added. $2\frac{1}{2} + 7\frac{3}{4} \times 10\frac{1}{4}$ *tons.* A $\frac{7}{8}$ in. rope is then required (Table 543).

543. Table Galvanized Iron Guy Rope. (Waterbury Company.)

6 Strands—7 or 12 Wires to the Strand—1 Hemp Core

Diam. in inches	Circumference in inches	Approximate weight per foot in pounds	Approximate strength in tons of 2000 pounds	Circumference of manila rope of equal strength, inches	List price per foot: 7 wires per strand	List price per foot: 12 wires per strand
1 3/4	5 1/2	4.85	42	11	$0.44	$0.46
1 11/16	5 1/4	4.42	38	10 1/2	.41	.43
1 5/8	5	4.15	35	10	.38	.40
1 1/2	4 3/4	3.55	30	9 1/2	.35	.37
1 7/16	4 1/2	3.24	28	9	.31 1/2	.33 1/2
1 3/8	4 1/4	3	26	8 1/2	.28 1/2	.30 1/2
1 1/4	4	2.45	23	8	.25	.26 1/2
1 3/16	3 3/4	2.21	19	7 1/2	.22 1/2	.24
1 1/8	3 1/2	2	18	6 1/2	.19 1/2	.21
1 1/16	3 1/4	1.77	16.1	6	.17 1/2	.18 1/2
1	3	1.58	14.1	5 3/4	.15	.16
7/8	2 3/4	1.20	11.1	5 1/4	.13	Guy rope is now (Sept., 1919) being sold at the list prices shown in this table.
13/16	2 1/2	1.03	9.4	5	.11	
3/4	2 1/4	.89	7.8	4 3/4	.09	
5/8	2	.62	5.7	4 1/2	.08	
9/16	1 3/4	.50	4.46	3 3/4	.07	
1/2	1 1/2	.39	3.39	3	.06	
7/16	1 1/4	.30	2.35	2 1/2	.05	
3/8	1 1/8	.22	1.95	2 1/4	.04 1/2	
5/16	1	.15	1.42	2	.03 1/2	
					5 strands	
9/32	7/8	.125	1.20	1 3/4	.03	
1/4	3/4	.09	.99	1 1/2	.02 1/2	
7/32	5/8	.063	.79	1 1/4	.02 1/4	
3/16	1/2	.04	.61	1 1/8	.02	

544. The Lap of the Riveted Girth Joints of a Steel Stack may be Upward or Downward.—When the outside lap is downward (Fig. 426), there is a leakage of the soot through

the joint to the outside. Acids are carried by the soot and the paint may be destroyed and the stack thereby corroded. A joint of this type (Fig. 426) prevents the rain and snow from lodging and running to the inside of the stack. It offers

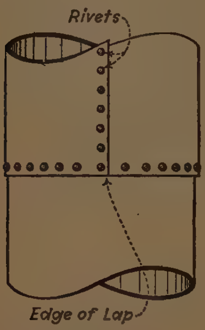


FIG. 426.—Girth joint of stack lapped downward.

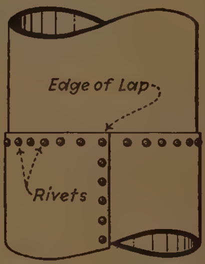


FIG. 427.—Girth joint of stack lapped upward.

minimum resistance to the flow of the flue gases. However, when the courses lap upward on the outside (Fig. 427), the joint may be made water tight by using putty of a certain kind.

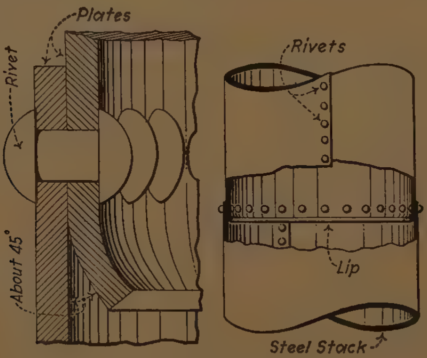


FIG. 428.—Lip turned on edge of inside lap.

Thereby leakage to the inside is prevented. The joint may be calked if it is required that it be exceptionally tight. To prevent the trickling liquid, which may contain acid and which runs down the inside of the stack, from being drawn into

the joint by capillary attraction, a lip (Fig. 428) is sometimes turned on the uppermost courses.

545. In proportioning the riveted joints in a steel stack the rules of practice require that the pitch, or distance from center to center, of the rivets be approximately 2.5 times the rivet diameter, provided this factor gives a pitch (Fig. 429) less than 16 times the thickness of the plate. If the latter provision is not fulfilled, a factor less than 2.5 must be used. Also, it is required that the rivet diameter be greater than the thickness of the plate, but never less than 0.5 inch. Single riveting is usually employed for all joints except the base joint (Fig. 430) where staggered double riveting is used. In stacks of very large diameter all circular seams are double-riveted to insure rigidity.

546. Stone Chimneys are Seldom Built.—The principles involved are very little different to those relating to brick chimney construction.

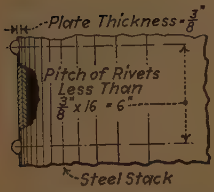


FIG. 429.—Section of vertical seam illustrating maximum allowable pitch of rivets.

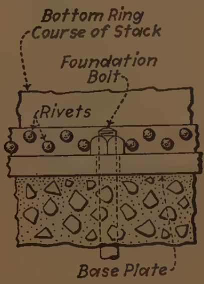


FIG. 430.—Showing double-stagger riveted joint at base of stack.

FIG. 431.—Single-shell brick chimney.

547. Brick is Widely Used for Building Chimneys.—The two types of brick chimneys are: (1) *The single-shell* (Fig. 431). (2) *The double-shell* (Fig. 432). The single-shell chimney is serviceable only where brick of an especially good quality and not affected by heat is available. The double-shell, *i.e.*, the lined chimney, is the most common type. The lining is independent of the outer wall thus allowing each wall to expand and contract freely without affecting the other.

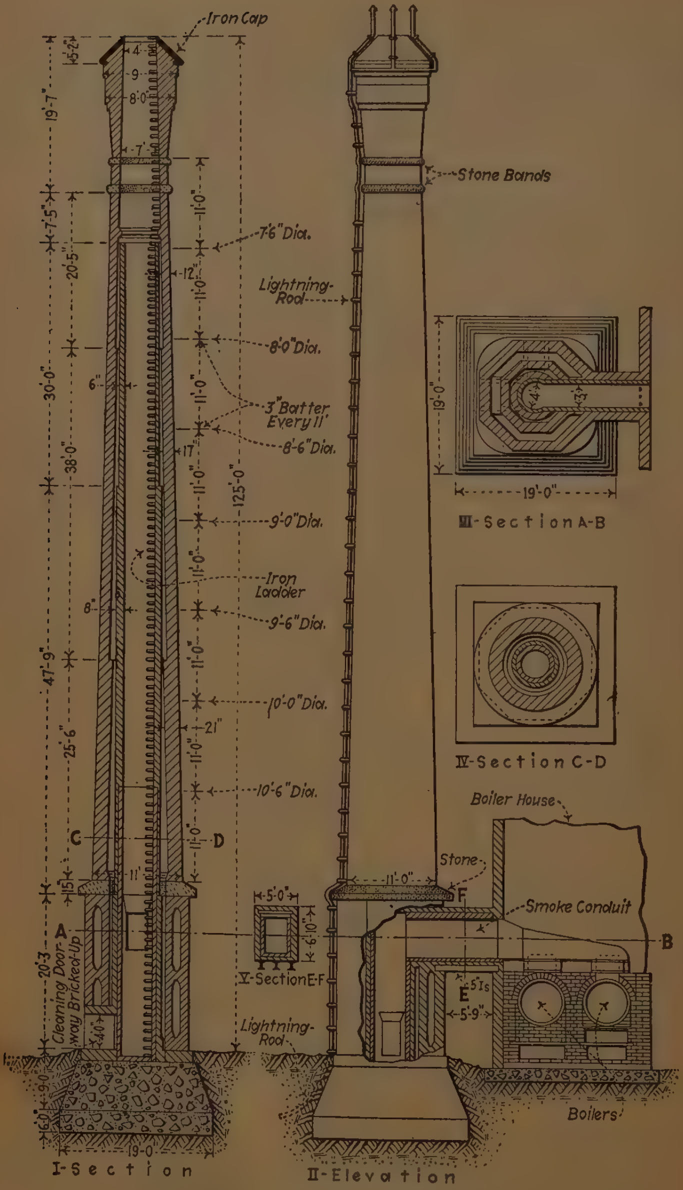


FIG. 432.—Double-shell brick chimney.

548. Buttresses are Sometimes Sprung from the Outer Shell to Stay the Inner Shell (Fig. 433).—This allows the inner shell to expand without interference. The buttresses should be spaced equally and should stand at least one inch clear of the inner shell. There are usually eight of them.

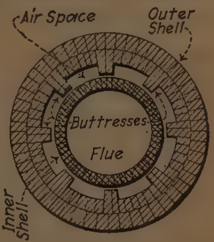


FIG. 433.—Horizontal section of brick chimney.

549. The annular space between the two shells should be at least 2 inches at the top. The batters of the shells should be so adjusted as to increase this distance to 8 or more inches at the bottom.

550. The thickness of brick chimney walls should be so proportioned as to secure stability with the minimum weight of material consistent with the practical requirements of mason work. Facility of construction requires that the thickness diminish abruptly, from bottom to top, in a series of steps or courses, as indicated in Fig. 434, instead of thinning out gradually.

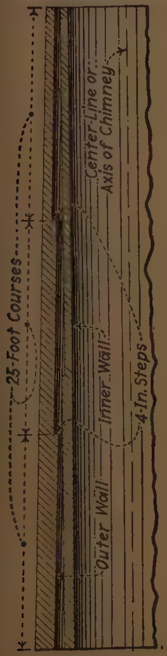


FIG. 434.—Showing stepped construction of chimney wall.

551. The thickness of the top course of an outer shell built of common brick may be found by the empirical formula:

(88) $L_t = 4 + 0.05d_i + 0.0005L_h$ (thickness, inches)

Wherein: L_t = thickness of top course, in inches. d_i = inside diameter of chimney at the top, in inches. L_h = height of chimney, in inches. The practical thickness is taken as that nearest to which the chimney can be built with brick.

552. Each succeeding course of 25 or 30 feet, starting at the top of the chimney, should be increased in thickness about 4 in.

EXAMPLE.—If a chimney is 100 ft. high and the top is 8 in. thick, it might be built of 4 courses each with height of 25 ft. Each course would increase 4 in. in thickness; thus they would be 8, 12, 16, and 20 in. thick.

553. The materials for brick chimneys should be hard-burned close grained bricks for the outer shaft and second-class fire bricks for the core. The outer brick work from the foundation up to a plane where the winds will have a fair sweep against the chimney should be laid in lime mortar well strengthened with cement. The upper portion should have a certain resiliency to offset the stress of high wind pressure, and this is best secured by the use of lime mortar containing a smaller admixture of cement. The proportions for the lower part may be 1 part of cement, 3 of lime, and 8 of sand. For the upper part they may be 1–2–6. Since lime does not cling tenaciously to hard, smooth surfaces the harder the brick the more the cement that should be used. The core should be laid with pure lime mortar or fire clay. Cement mortar should not be used for any part of the core because it disintegrates in the presence of carbon dioxide and high temperatures.

554. Radial bricks are preferable to common bricks for building round chimneys. As they provide a better appearing and stauncher job. Radial bricks, illustrated in Fig. 435, are

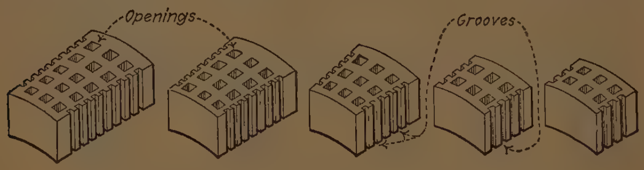


FIG. 435.—Radial brick for chimney building.

made with different radii, to suit all degrees of curvature. They can be laid Fig. 436 more compactly than common brick, which require thick mortar joints to fill out the irregularities. A circular column built of these radial bricks makes a very strong structure, because the bricks are virtually keyed in. Each brick in a course acts to hold the entire course intact, like the keystone in an arch. In addition, strength against cracking is added by laying steel bands within the wall.

555. Radial bricks are perforated vertically with square holes. The weight of the brick is thus reduced. Furthermore the facility which the holes give for thorough burning insures added strength and density. The mortar is worked into the

perforations to a depth of about half an inch. The aggregate body of air confined in the multitude of pockets formed by the perforations acts to insulate the structure against heat transference. Hence the radiation is less from a radial brick structure than from one of solid brickwork.

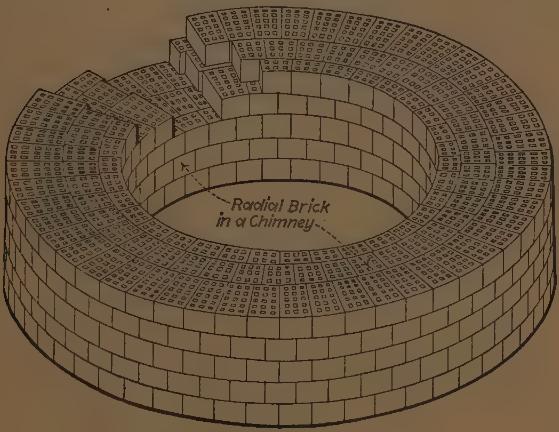


Fig. 436.—Section of chimney.

556. A method of reinforced tile-concrete construction for power plant chimneys is illustrated in Fig. 437. The hard-burned fireclay tiles (Fig. 438) used with this method make permanent forms for the concrete. The concrete is reinforced with steel bars, as shown in Fig. 437. The successive vertical bar-lengths are made to overlap sufficiently at their ends to develop full strength at the joints. Thus, a practically continuous steel reinforcement from the base to the top of the chimney is assured.

557. The Concrete Foundation is Reinforced with Twisted Steel Bars.—These are placed in layers running alternately, parallel with the sides and diagonally across the foundation.

The first circular row of vertical reinforcing bars for the super-structure are deeply embedded in the foundation, with their lower ends bent to better secure an anchorage in the concrete. Thus the foundation and chimney are made to form a monolithic mass. The first course of tile is set in a bed of cement mortar and is filled to about two-thirds of its height

with concrete, which is firmly tamped into place. A steel ring is then set horizontally on the concrete, after which the circle of tile is filled for the remainder of its height. A layer

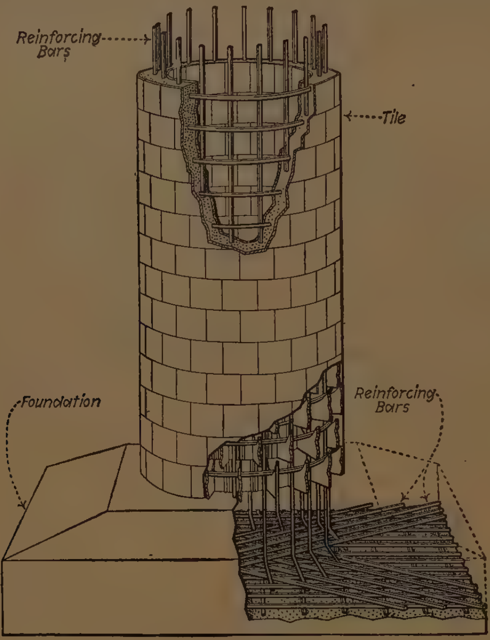


FIG. 437.—Wiederholdt chimney.

of cement mortar is spread upon the course thus formed and the next course is similarly laid; and so on up. The joints of each succeeding course alternate with those of the preceding course.

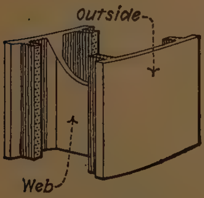


FIG. 438.—Tiles for Weiderholt chimney.

558. Reinforced Concrete Chimneys are Desirable for many Reasons.—They may be built rapidly. They (Fig. 439) are strong, because they are reinforced with steel rods which take the tension on the windward side. They are light, thus permitting smaller foundations than are required for brick stacks. They do not occupy so much space as brick chimneys. The interior is smooth, thus minimizing friction.

As concrete chimneys are practically air tight, there is no air leakage which might decrease the effective draft pressure. Disintegration of concrete stacks by the weather is not so noticeable as in steel stacks. The material for construction may be secured in the vicinity, thus reducing transportation expense. Typical construction is shown in Fig. 439. Reinforced concrete chimneys should be specially designed by an experienced concern or engineer.

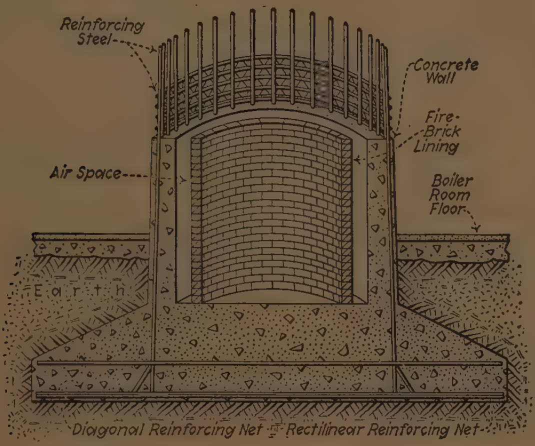


FIG. 439.—Reinforced concrete chimney construction.

559. Removing the soot from the base of a chimney, where the plant is in continuous operation, should be done with due regard for comfort and cleanliness in the neighborhood of the plant. Flushing the soot out with a stream of water (Fig. 440) is a good way to accomplish this.

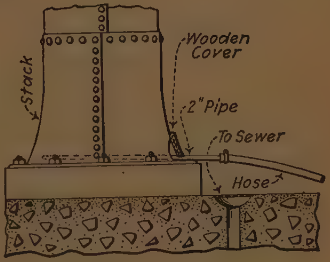


FIG. 440.—Arrangement for flushing out soot from base of stack.

EXAMPLE.—A section of 2-inch pipe, attached to a length of fire-hose, is inserted through the clean-out opening at the base and extended very nearly to the opposite side. The clean-out door is temporarily replaced with a wooden cover which has an opening at its lower edge large enough for admission of the pipe and for the issuance of the mingled

stream of water and soot. As the soot is washed out from the bottom of the pile, the upper surface remains undisturbed.

560. The top of a brick chimney should be protected from the weather by a cast iron cap (Fig. 441). At least four ⅞-inch copper studs, for securing the cap, should be left projecting upward from the brickwork at the top. The studs should be riveted over after the cap is set in place.

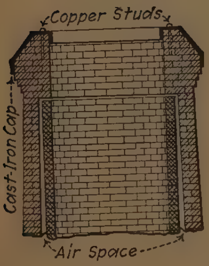


Fig. 441.—Top of brick chimney.

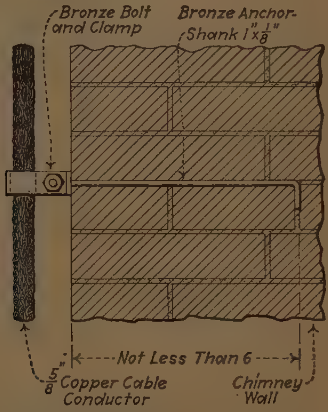


Fig. 442.—Anchor clamp for securing cable to chimney wall.

561. For protecting masonry chimneys from lightning damage (steel chimneys seem to be immune when grounded), the standard specifications adopted by the United States Navy yard power plants may be followed.

Note.—The U. S. Navy specifications require from 2 to 4 lightning conductors, according to the height of the chimney. Where the chimney is 50 ft. or less in height there are required two conductors; 50 to 100 ft.; 3 conductors; 100 ft. and higher, 4 conductors. The conductors are of seven-strand copper cable of approximately ⅝-in. diameter and arranged symmetrically about the chimney. Each conductor is anchored to the chimney wall by bronze or brass clamps (Fig. 442) in which the cable is clamped at intervals of 10 ft. Every fifth clamp is further secured with solder.

At their upper ends, the conductors are attached to a 1½ in. × ½ in. copper ring, which encircles the chimney 5 feet below the top (Fig. 443) The ring is bolted to bronze or brass brackets which are anchored in the chimney wall (Fig. 444) and spaced not over 2 ft. apart. The cable connections are shown in Fig. 445.

A number of upwardly-projecting terminal rods (Fig. 443), ¾ in. in diameter and at least 10 ft. long are attached to the copper ring (Fig. 446) at equidistant locations not over 4 ft. apart. These terminal

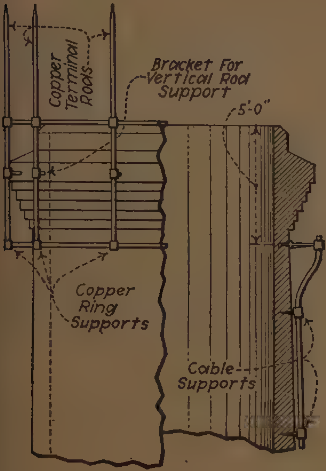


FIG. 443.—Elevation, half sectional, of chimney top, showing terminal rods.

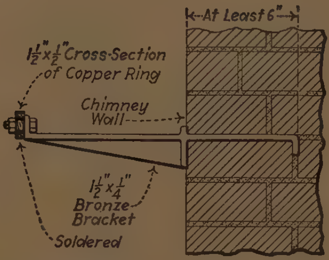


FIG. 444.—Anchor bracket for securing copper terminal ring to chimney wall.

rods are rigidly supported by brackets which are anchored in the masonry (Fig. 443) and supplemented by a copper spider resting on top of the chimney (Fig. 447). The rods of the spider are secured to the terminal rods as shown in Fig. 448.

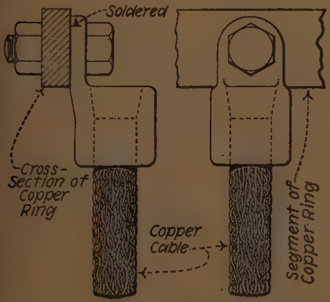


FIG. 445.—Showing attachment of lightning conductor to copper terminal ring.

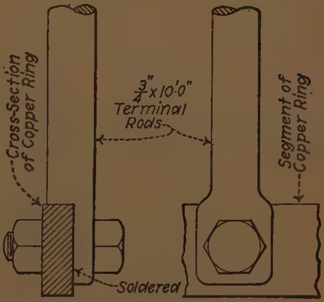


FIG. 446.—Attachment of terminal rods to copper ring.

Each terminal rod or *point* is shielded from the corrosive effects of the chimney gases by a thin sheathing of lead which, in accordance with the

Navy specifications, extends down about 2 ft. from the point (Fig. 448). At the base of the chimney, each conductor cable is enclosed in a $1\frac{1}{2}$ in. galvanized iron pipe extending 3 ft. into the soil and 10 ft. above. The

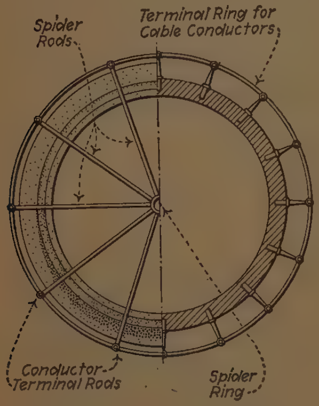


FIG. 447.—Plan of chimney top, half sectional, showing copper spider for securing terminal rods.

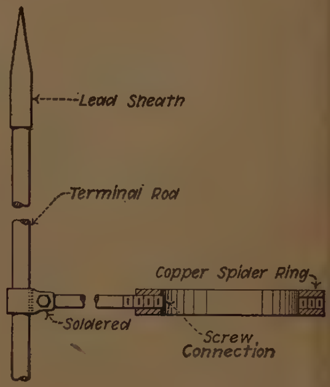


FIG. 448.—Details of copper spider, showing attachment to terminal rod.

cable is electrically connected to the top and bottom ends of the pipe by driving in a metal wedge between the cable and the pipe. The lower end of each cable is securely attached, both mechanically and electrically, to $3 \times \frac{1}{2} \times 36$ in. pure copper earth-bars (Fig. 449). The earth bars are set below the ground water level—in no case less than 15 ft. below the surface.

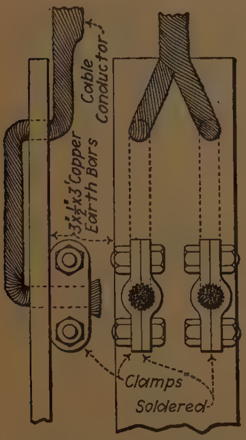


FIG. 449.—Details of earth bar for grounding lightning conductors.

562. All Lightning Conductors near the Top of the Chimney should be Sheathed with Lead.—Although some specifications are more liberal, best practice dictates that all copper located above and all within 2 ft. below the top should be sheathed in lead. The specifications of some of the most experienced and prominent engineers so direct.

563. While a square masonry chimney is the easiest to build, it is not desirable because the draft which it handles is not so good as that produced by a chimney of equal flue area and round

section. This is due to the greater friction offered by sharp internal corners of the square chimney. The area of a square is not as large as the area of an octagon or circle with the same perimeter. Hence, a larger flue is available with same material if the chimney is round in section. A round chimney gives from 1 to 2 per cent. stronger draft pressure than a square one of the same flue area.

564. The diameter of the base of chimney is often taken as 1⁄10 to 1⁄8 the height. But this should not be accepted as a definite rule.

565. In computing depreciation of stacks, brick stacks are assumed to have a *life* or *expectancy* of about 33 years (Chicago Traction Co. Case and from Chicago Appraisals by Floy) and steel stacks an expectancy of 12 to 14 years (San Francisco Rate Hearings in 1913 and 1914 and from Chicago Appraisals by Floy).

566. Table showing comparative approximate costs of chimneys (Mechanical Engineers' Handbook, Marks). All costs include foundation material and erection. Freight is not included in steel stack costs. Costs of brick and concrete stacks will vary from 5 to 15 per cent. with local prices. Total cost of steel stacks will vary with freight charges.

Height, ft.	Diam., in.	Horse power	Brick cost	Concrete cost	Self-supporting steel		Guyed Steel	
					Weight, lb.	Cost	Weight lb.	Cost
100	42	258	$1,400	$1,300			8,250	$ 420
150	54	551	2,700	2,150			21,080	850
150	72	1,023	3,500	2,800	51,750	$2,200	31,450	1,230
175	84	1,531	4,300	3,500	76,250	3,250	53,230	2,075
200	96	2,167	5,600	4,500	108,100	4,600		
200	120	3.448	7,200	5,800	117,000	4,975		
225	132	4,455	8,700	7,000	155,900	6,650		
250	144	5,618	10,000	8,100	206,800	8,800		

567. The Term "Smoke Conduit," as used in this Book, Designates The Smoke Passages Between the Boiler or Boiler-setting and the Chimney.—Such connections are designated in various ways by different writers and manufacturers. A smoke conduit may be made of any suitable material. The

most common is sheet or plate steel which is formed and riveted into the desired shape. But where the smoke conduit is large or supported on or is under ground, it may be of brick concrete, or other suitable masonry material, which will not be injured readily by the heat and flue gases.

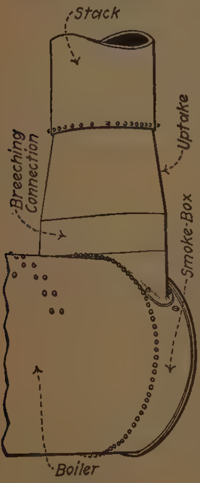


FIG. 450.—Simple breeching.

568. The term "breeching" shall be used herein to indicate such smoke conduits as are made of sheet or plate steel. When the breeching is vertical or at a steep angle as referred to the horizontal, it shall be called an *uptake*. An example is shown in Fig. 450 wherein the stack is connected to the smoke box by the vertical, oval, conical uptake breeching.

569. A "smoke connection" (Fig. 451) is a simple approximately-horizontal breeching which leads directly from the boiler into the chimney. Such breechings are used often in heating-boiler installations.

570. An "underground smoke" conduit is a conduit through which the combustion-gases are carried underground to the

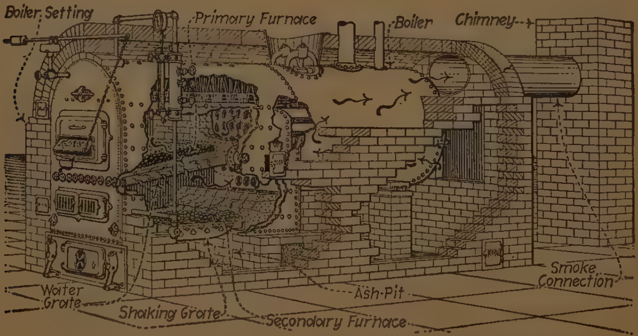


FIG. 451.—Horizontal smoke connection on Kewanee boiler.

chimney. Such conduits are seldom installed, except where it is necessary to satisfy some special requirement. An underground smoke conduit is shown in the frontispiece of this book.

571. Underground Smoke Conduits are Undesirable.—It is difficult to clean them. Furthermore the gases passing through may be chilled and hence the effective draft pressure is decreased. The cleaning of the breechings above the ground is easily effected through the doors which may be provided. If water can get into the underground conduit, it will evaporate and cool the gases as they pass through, thus taking away the draft power of the gases.

572. A common type of breeching connection for one boiler is shown in Fig. 452. It is called a *side breeching*. It leads

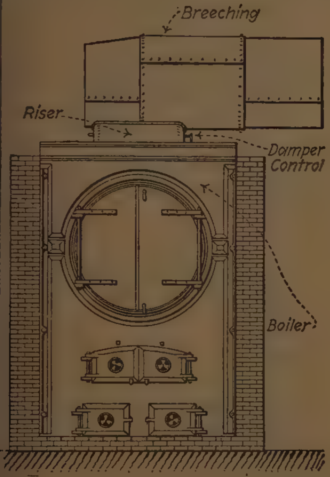


Fig. 452.—Side-breeching for one boiler.

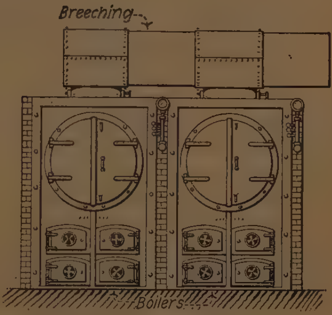


Fig. 453.—Horizontal breeching for two boilers.

horizontally to the chimney. The riser is oval in section and the horizontal conduit is circular. Note that the damper is in the riser.

573. The arrangement of the breeching where two boilers are served by one chimney (Figs. 453 to 462 inclusive) may follow any one of a number of different designs. Which should be adopted in any given installation, must be determined by a consideration of the local conditions which must be satisfied.

574. The breeching arrangement where three or more boilers connect to one chimney will now be considered. Figs. 463 and 464 show *triple side breechings* while Figs. 465 and 466

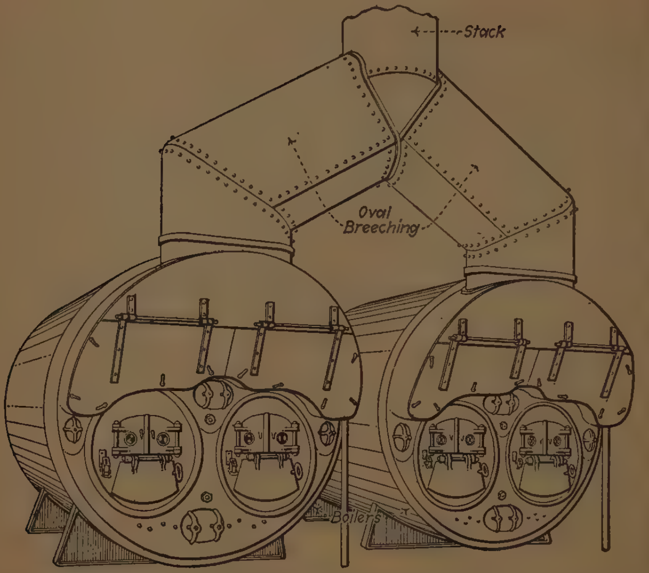


Fig. 454.—Two boilers connected to one stack by oval Y-breeching.

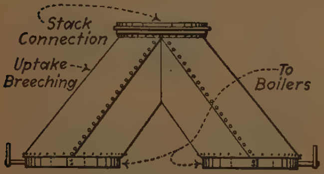


Fig. 455.—Circular inserted Y-breeching.

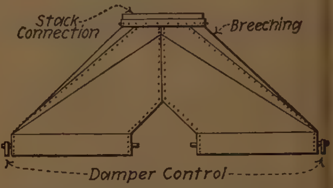


Fig. 456.—Inverted Y-breeching for rectangular breeching connection.

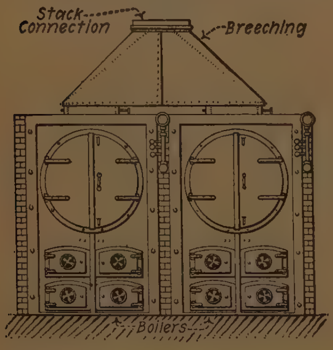


Fig. 457.—Inverted Y-type breeching.

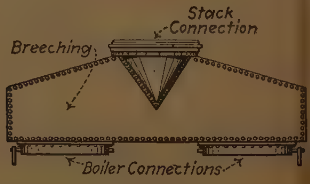


Fig. 458.—Rectangular center-connection breeching for two boilers.

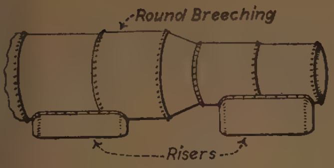


FIG. 459.—Round side-breeching for two boilers.

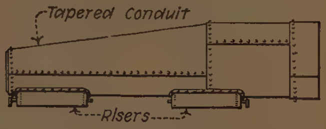


FIG. 460.—Round tapered breeching.

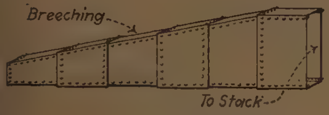


FIG. 461.—Rectangular side-breeching for two boilers.

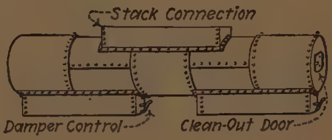


FIG. 462.—Center connection breeching.

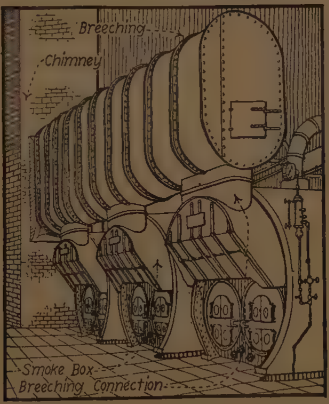


FIG. 463.—Triple side-breeching on 3 boilers.

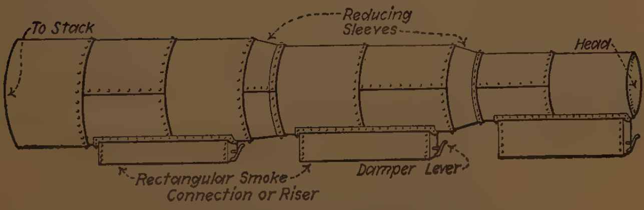


FIG. 464.—Triple side-breeching.

show *triple breechings with center entrance* to the stack. When a breeching of the type of Fig. 466 is used, unless the dampers are adjusted carefully, the center boiler is liable to have the

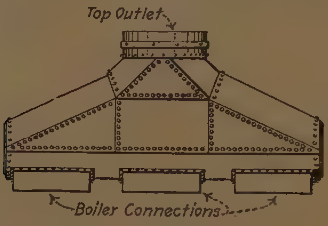


FIG. 465.—Triple breeching with top outlet.

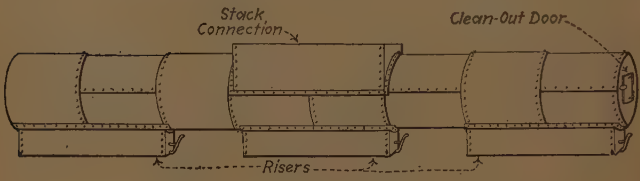


FIG. 466.—Center connection triple breeching.

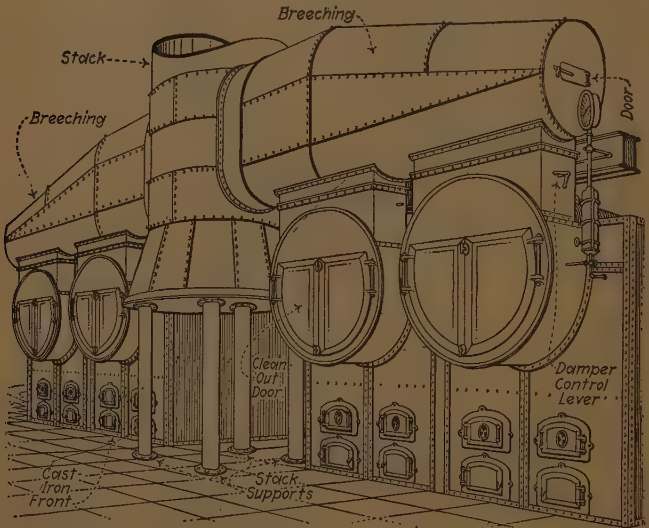


FIG. 467.—Four boilers connected to one stack (Casey Hedges Co.).

best draft pressure. Fig. 467 shows four boilers, set in pairs, which have a common chimney connection through two

louble side breechings. Note that the stack does not rest on he breeching but is separately supported. Fig. 468 shows the

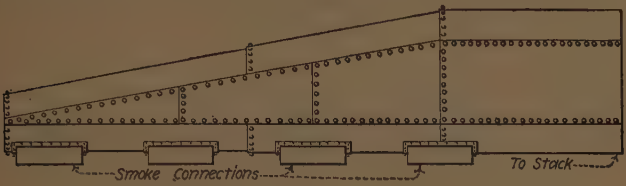


FIG. 468.—Horizontal breeching for four boilers.

side breeching for four boilers. The section is oval, as in those of similar type arranged for the double and triple connection.

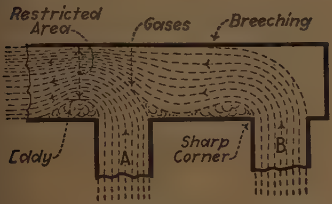


FIG. 469.—Gas path in square-corner breeching. Better draft in *A* than *B*.

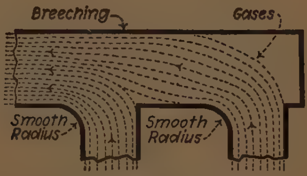


FIG. 470.—Gas path when breeching has curved unions.

575. In Designing Breechings, Outlet Shapes which have Sharp Bends should be Avoided.—Sharp bends cause an unnecessary loss or drop in draft pressure, making it necessary

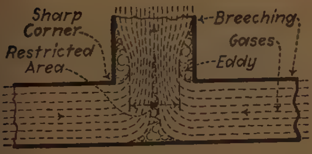


FIG. 471.—Effect of square-cornered riser from horizontal double breeching. Area restricted.

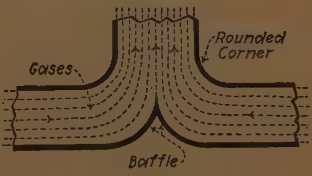


FIG. 472.—Breeching which conducts gases along smooth path.

to install a stack higher than would otherwise be necessary to overcome their effect. See Div. 19. Figs. 469 and 470 indicate the results in a double outlet breeching when the

corners are square and rounded. Fig. 471 shows the effect of a sharp angle where an uptake joins a horizontal breeching. The area is much restricted and the effective draft pressure is reduced. Fig. 472 shows the gases passing without interruption. The path of the gases into the stack may be improved by having (instead of the straight baffle shown in Fig. 473 a curved baffle such as shown in Fig. 473.

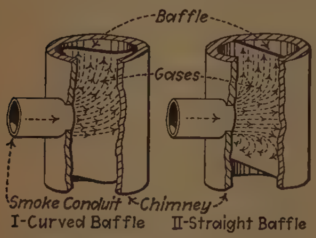


FIG. 473.—Union of smoke conduit to stack.

576. A Smoke Conduit of Round Cross Section Carries More Gas for the Same Area than Does a Square One.—If tested, it would be found that the gases in the corners of the square conduit would be practically stagnant for some distance out from the corner. The curve indicating the velocity of the gases would rise slowly (Fig. 474). This means that the average velocity of the gases is lowered for the whole area.

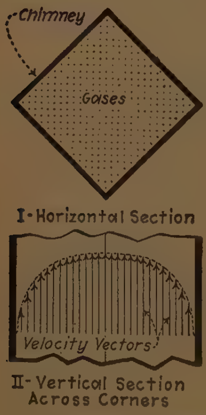


FIG. 474.—Velocity of gases in various parts of square flue.

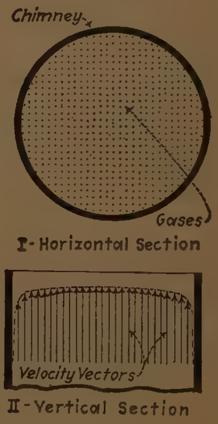


FIG. 475.—Velocity of gases in various parts of round flue.

Consequently the volume of gas that passes is decreased. In the round conduit (Fig. 475) the gas is stagnant only along a thin film at the periphery of the passage. The velocity curve

rises rapidly. The average velocity of the gases is decreased but little. Hence the amount of gas passing, with the same draft pressure, is greater than for an equal square section.

577. The area of the smoke conduit should not be changed abruptly. Such a change will cause a decrease in the draft pressure. The area of the smoke conduit is usually greater than the opening in the chimney, by at least 10 per cent. Misostow (THE NATIONAL ENGINEER, Feb. 1913) specifies an area of smoke conduit at least 25 per cent. greater than the tube or flue area.

578. Steel smoke conduits should be covered to prevent the radiation of the heat of the gases. When the flue gases are cooled the difference between the density of the gases and that of the outside atmosphere is decreased. Hence the draft pressure is reduced correspondingly. A lining may be placed inside of the breeching but one so located is difficult to repair and keep in place. An outside heat-insulating covering is preferable.

579. Steel smoke conduits are preferable to those of brick or concrete because the friction of the flowing gases on the steel is less than on the other materials. Furthermore the steel interior surface is smoother and may be cleaned more readily than can brick or the rough masonry.

580. The Thickness of the Steel Plate Used for a Breeching should be Determined by Local Conditions.—If a tall stack is to rest upon the breeching it should be made of heavier material than otherwise and braced with angles so arranged that the stack will be well supported. The riveting should be about the same as for the stack. Care should be taken that all seams are well closed, for leakage decreases the effective draft pressure.

NOTE.—Ordinarily, breechings are made of No. 8 (0.172 in.) and No. 10 (0.141 in.) U. S. Standard Gage steel plate. For small work Nos. 12, 14, and 16 Gage plate may be used. Better construction calls for 3/16 in. plate. Some concerns will use no plate thinner than 3/16 in. It costs but little more than lighter stock and has a much longer life, particularly when exposed to extreme conditions. Rivet diameters for plates of the different thicknesses are usually: No. 14 and 16—1/4 in.; No. 12 and 10—5/16 in.; No. 8, 3/8 in. The pitch is usually about 3 in. unless the breeching must support an external load in which case correspondingly smaller pitches should be used.

581. When the Stack Rests upon the Breeching, the Weight of the Whole should not be Supported by the Boiler Shell.—If the stack is heavy the smoke box extension may collapse. A stack and breeching support of some description should be used. Fig. 476 illustrates such a support the girder of which bridges the boiler. The weight is assumed by the girders and the columns at the sides.

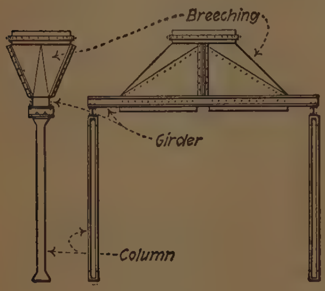


Fig. 476.—Breeching and stack support.

582. Draft Pressure should be Controlled by Damper Adjustment.—Often combustion is regulated by means of the draft door or by the amount of air that is admitted to the combustion chamber. The resulting combustion may be poor, as compared to that which is possible to attain by damper control.

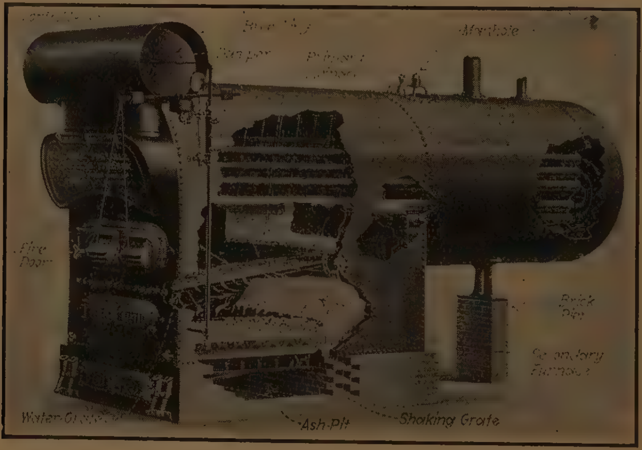


Fig. 477.—Damper in breeching (in Kewanee down-draft boiler).

583. A Damper is usually placed in each Smoke Conduit or Riser, so that the draft pressure in each boiler may be controlled individually. By referring to the accompanying illustrations of breechings, it will be noted that the location of the damper

is generally in the riser leading into the main part of the breeching. Fig. 477 illustrates the location of a damper in a breeching which is round in section and connected to one boiler. Other illustrations in this book show the position of the damper in a boiler setting just in front of the location where the breeching proper begins.

NOTE.—By means of automatic-control devices, which operate through the damper-control lever, the damper may be automatically opened and closed so as to provide the proper draft to insure combustion at a proper rate to maintain the steam pressure constant. Such apparatus are discussed in the Division on BOILER ACCESSORIES.

NOTE.—THE DAMPER IS OFTEN A CASTING, or it may be steel plate. Ordinarily ¼-in. plate is used. For the larger sizes, the plate is reinforced with steel angles. Often the damper trunnions turn in bronze bushings.

NOTE.—THERE IS A LOSS OF DRAFT EVEN WHEN THE DAMPER IS WIDE OPEN, hence the damper opening should be slightly larger than the flue opening in the chimney.

QUESTIONS ON DIVISION 20

1. Define a power plant chimney.
2. What is the difference between a chimney and a stack?
3. Are the terms *chimney* and *stack* always understood to mean different things?
4. What two constructional requirements may be mentioned?
5. Of what material may a chimney be built? Why may a certain material be selected?
6. What are the prlncipal agents tending to destroy a chimney? Discuss.
7. How does the heat from the combustion gases affect an unlined masonry chimney with a thick wall?
8. Why is a lining built inside the masonry or steel stack?
9. What determines the height to which the lining should extend?
10. What is the procedure in designing a masonry stack?
11. What calculations and considerations are to be considered in designing a self-supporting steel stack?
12. Why should a chimney be tall and have a large flue area?
13. What are the tendencies due to wind blowing against a chimney?
14. What are the maximum assumed wind pressures that may be employed in designing a chimney?
15. State and discuss the meaning of the formula for determining the wind pressure against a stack.
16. What is *batter* as referred to chimneys? Why have it?
17. How is the total pressure, due to wind, against a chimney calculated?
18. What is meant by the "center of gravity of the projected exposed area"?
19. How is the height of the center of gravity of the projected area determined? Give two methods.
20. If calculations show that the pressure under a foundation of a chimney is too great, what should be done?
21. When the supporting soil is uncertain, what may be done to insure that the foundation will not settle?
22. How is the bearing area of a foundation determined, when the allowable pressure on the soil and the weight of the chimney are known?
23. What is the tendency of a chimney when a strong wind blows against it?

24. State the formula used in computing the maximum pressure, due to wind, under the leeward edge of the foundation.

25. How is the total maximum pressure, due to wind and weight, under the leeward side of foundation determined?

26. If the weight is not sufficient and the foundation not large enough, what would be the result when a strong wind blows against the chimney?

27. How is the distance from the axis of the chimney to the point where the resultant pressure cuts the section determined?

28. For a stable structure how far from the axis of the chimney may the resultant pressure cut the base line?

29. When there is no wind blowing against a chimney, what stress is imposed?

30. How may the compressive stress on each square inch due to dead weight be calculated?

31. Neglecting the weight of the stack, what are the stresses set up when the stack is in a strong wind?

32. How is the total compressive stress on the leeward side of the stack determined? How is the net stress on the windward side determined?

33. If a chimney be constructed of a material that may buckle, what formula is commonly used for determining its safety?

34. When a chimney is resting on a square foundation, will the maximum stress under the foundation be greater when the wind is blowing across diagonally or when blowing perpendicular to one of the sides of the foundation?

35. How may steel stacks be classified?

36. What is the advantage of building a steel stack in the boiler room midway of the building?

37. When is it necessary to brace or guy a chimney?

38. Why should a stack which rests on a boiler breeching have two sets of guys?

39. How should the guy ropes be fastened to the stack?

40. Describe the method of determining the proper size of a guy rope.

41. Should the vertical downward force due to the vertical component of the pull exerted by the guy ropes be considered in designing the stack and foundation? Discuss.

42. What may be said concerning the upward and downward lapping of the riveted girth joints?

43. What are the rules for steel stacks concerning the proportions of rivets, rivet spacing, etc.?

44. Are stone chimneys commonly built?

45. May the inner wall of a double-wall brick chimney expand without affecting the outer wall?

46. By what means is the inner wall stayed to prevent it from leaning to one side of the space inside the outer shell?

47. What is the minimum distance to be allowed between the outer wall and the inner wall of a chimney?

48. Is the wall of a brick chimney thinned out gradually toward the top or abruptly? Why?

49. What factors determine the thickness of the chimney wall at the top?

50. What is the usual practice concerning the increase, beginning at the top, in the thickness of a brick chimney?

51. Describe the materials used in constructing a good brick chimney.

52. Describe the radial brick chimney? Is it desirable?

53. What is meant by a reinforced tile-concrete chimney?

54. Is a concrete chimney a desirable chimney? Why?

55. Describe a good method of removing soot from the base of a chimney?

56. Why place a metal cap on a chimney?

57. Are lightening rods desirable on chimneys? What specifications may be followed in placing rods on the chimney? Describe a typical installation.

58. Why is a square chimney undesirable?

59. What is a common proportion of the diameter of a chimney foundation with respect to the height of the chimney?

60. What may be assumed to be the useful life of a chimney?

61. What is a smoke conduit?

62. Differentiate between the following terms: *breeching, uptake, smoke connection, underground smoke conduit.*

63. Describe a form of *side breeching* for one boiler.

64. Draw sketches showing connections of two, three and four boilers to one stack.

65. Why should a sharp bend in a breeching be avoided? Explain.

66. Why is a round smoke passage better than a square one of equal area? Explain with a sketch.

67. Why is an underground smoke conduit undesirable?

68. As compared to flue area, what should be the area of a breeching?

69. How can the cooling of the gases in a breeching be decreased? Why is this desirable?

70. Discuss the thickness and construction of steel breechings.

71. How may the imposing of the weight of a steel stack on the boiler shell be avoided?

72. Why is a damper desirable? Where is it placed?

73. Does the damper, when open, retard gas passing through a breeching?

PROBLEMS ON DIVISION 20

1. An octagonal chimney is in a wind having a velocity of 80 mi. per hour. What is the pressure per square foot of projected area?

2. When a pressure of 30 lb. per sq. ft. is applied to the projected area of a chimney which is 120 ft. high, 8 ft. across at the top and 9½ ft. across at the bottom, what will be the total force against the chimney?

3. Determine the distance from the ground to the center of wind pressure of the chimney of Prob. 2.

4. When the wind exerts a force of 25,000 lbs. against a chimney with center of pressure 52 ft. above the bottom of its foundation, what will be the maximum pressure caused by wind alone under a 16 ft. square foundation? (I/c for solid square = $0.118L^3$ where L = length of one side).

5. If the chimney and foundation of Prob. 4 weighs 300 tons, what is the total maximum load under the foundation when the wind is blowing as in Prob. 4?

6. Assuming a total wind pressure against a chimney of 30,000 pounds acting at 45 ft. above the foundation and a structure weighing 600,000 pounds what will be the distance from the axis of the chimney to the point where the resultant force cuts the section?

7. A certain chimney weighs 485 tons above a certain section which is circular. The inner diameter is 8½ ft. and the outside diameter 11 ft. What is the stress imposed on each square inch?

8. If the chimney in Prob. 7 is subjected to a wind pressure of 40,000 lb. assumed as at 60 feet above the section considered, what will be the increased compression on the leeward side? (I/c for hollow circular section = $0.7854\ [(r_o^4 - r_i^4) \div r_o]$.

9. What is the total compressive stress on the leeward side of the chimney of Probs. 7 and 8? Is it safe for brick construction?

10. A certain steel stack is 175 ft. high and 11 ft. in outside diameter. The wind in a certain storm recorded 95 mi. per hour. What is the stress set up in the steel and is the stack safe when the material is ⅝ in. thick and single riveted?

11. The total horizontal force against a guyed chimney due to a strong wind is about 18,000 lb. If this chimney must be held upright by one guy rope which has an angle of 55 deg. with the chimney, what stress must the rope withstand? (Sine 55° = 0.819.) Referring to Table 534 what must be the diameter of the rope?

12. Determine by formula the thickness of the uppermost part of a brick chimney which is 225 ft. high and 11 ft. inside diameter at the top. What is the nearest practical value to be used; *i.e.*, a thickness which is a multiple of bricks 2 × 4 × 8 inches laid flat, allowing ½-in. for mortar joint?

DIVISION 21

ARTIFICIAL DRAFT EQUIPMENT

584. Artificial Draft may be used Instead of Natural Draft in any Boiler Plant.—But, if adequate means for its production are available, natural draft is preferable to artificial draft. The first cost of a chimney may be from two to four times greater than that of an equivalent artificial-draft system. But the operating and maintenance costs of the chimney will be comparatively insignificant.

Conditions Which Render Artificial Draft Necessary are the following: (1) *When, for any reason, it is practically impossible to build a chimney large enough to produce sufficient draft for the complete combustion of the requisite quantity of a predetermined quality of fuel per sq. ft. of grate area per hour.* (2) *Where underfeed stokers are used.* (3) *When the draft is introduced through hollow grate bars, such as are used in furnaces for burning bagasse.*

Conditions Which Render Artificial Draft Desirable are the following: (1) *When the apparent prospects, regarding the permanency of the plant, do not warrant the expense of building a chimney.* (2) *When the requisite rate of fuel consumption necessitates an excessively high chimney, thus making the initial expense excessive as compared with the expense of installing, maintaining and operating an artificial-draft system.* (3) *When the daily load has occasional high peaks of comparatively short duration.* (4) *When the chimney has been improperly designed and alterations are not feasible.* (5) *When the load imposed on a boiler plant exceeds that for which the plant was originally designed, and, with the chimney inadequate to force the existing plant, it is either impracticable or undesirable, for the time being, to increase the number of boilers.* (6) *When it is desired to substitute a grade of fuel which will require, for its combustion, a more intense draft than the chimney will afford.* (7) *When economizers are installed in conjunction with the boilers in new plants, and, particularly, when they are added to existing boiler plants.*

For a discussion of *economizers*, see the Author's Steam Power Plant Auxiliaries and Accessories.

A Condition Which Renders Artificial Draft Neither Necessary Nor Desirable exists when there is available a chimney of ample height and cross-section to furnish the draft necessary for the complete combustion of the desired maximum quantity of the lowest grade of fuel that will be used.

NOTE.—Tests have shown that the capacity of a boiler, when working continuously, may be increased from 30 to 40 per cent. by the use of artificial draft. For short runs the capacity may be increased up to 100 per cent.

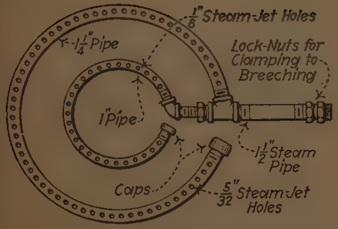


FIG. 478.—Ring or pipe-coil steam-jet blower (for use in breeching or stack).

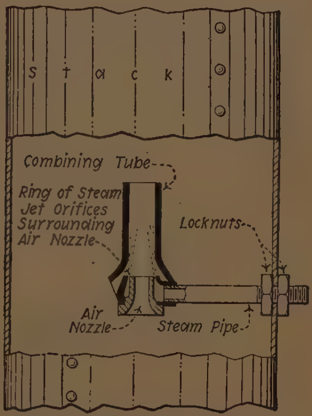


FIG. 479.—Bloomsburg ejector steam-jet blower installed for induced draft.

585. Artificial draft equipment for a boiler plant comprises two general classes of apparatus: (1) *Steam-jet blowers*

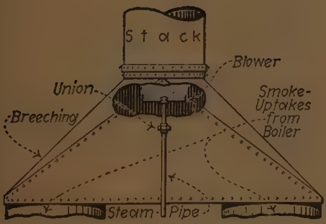


FIG. 480.—Ring or pipe-coil steam-jet blower installed for induced draft.

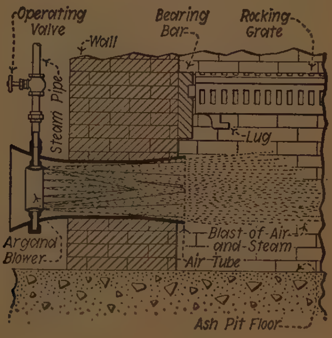


FIG. 481.—Argand type steam-jet blower installed in side-wall for forcing draft through ash-pit.

(Figs. 478, 479, 480 and 481). (2) *Fan-blowers* (Figs. 482, 483, 484 and 485). Fan-blowers are of two distinct forms of

construction, as follows: (1) *The disc or propeller type* (Figs. 482 and 483). (2) *The wheel or centrifugal type* (Figs. 484 and 485).

586. All artificial draft apparatus may operate in accordance with either of two general methods: (1) *Induction or suction,* as when the apparatus is installed (Figs. 479, 480 and 486) on the flue or stack side of the boiler-furnace and draws the air through the ashpit and grate. (2) *Propulsion, forced or pressure,* as when the apparatus is so located (Figs. 481, 483, 484, 487, 488 and 489) as to drive the air into the ashpit and through the grate.

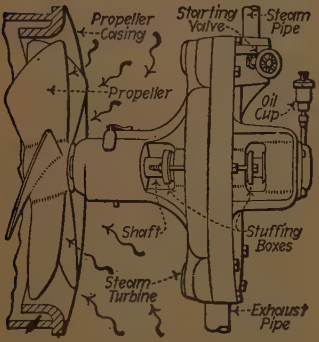


FIG. 482.—Propeller-fan blower driven, by steam turbine, through direct-shaft-connection (Power Turbo-Blower Co.).

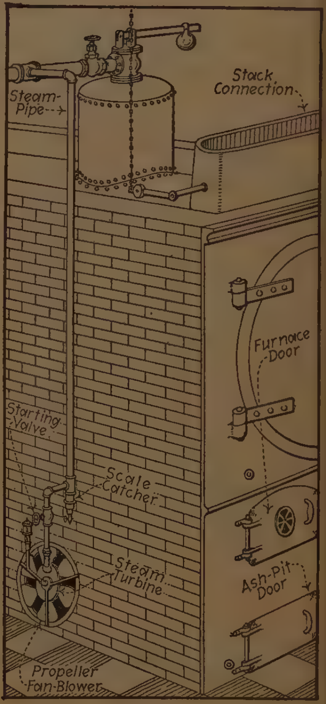


FIG. 483.—Propeller-fan blower installed in side-wall for forcing draft through ash-pit (Power Turbo Blower Co.).

587. Induced draft is artificial draft which is produced by the method of induction. With this method, the pressure of the air within the ashpit and furnace is always less than the normal atmospheric pressure.

588. Forced draft is artificial draft which is produced by the method of propulsion. With this method, the pressure

of the air within the ashpit and furnace is greater than the normal atmospheric pressure.

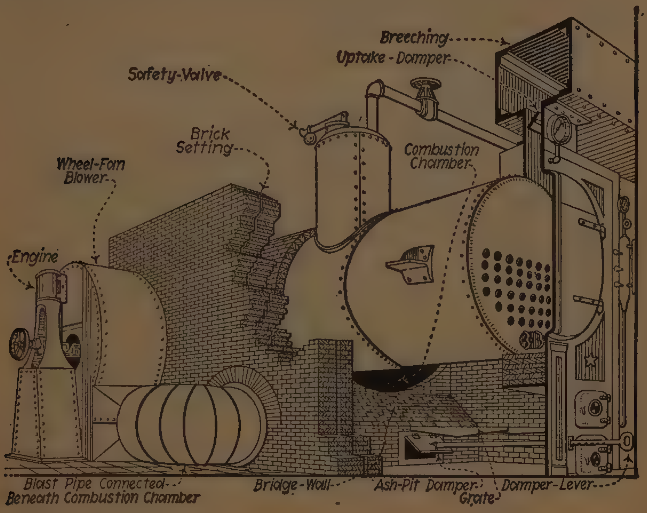


FIG. 484.—Wheel-fan blower installed for forcing draft through ash-pit (American Blower Co.).

NOTE.—Propeller-fan blowers are ill-adapted for induced-draft systems. Practically their sole employment, as artificial draft apparatus,

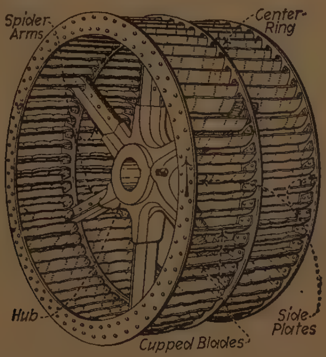


FIG. 485.—Multivane wheel-fan for high-speed operation (B. F. Sturtevant Co.).

is in comparatively small forced-draft systems. Wheel-fan blowers are well-adapted for either induced-or forced-draft systems of the largest size.

The Considerations Which Govern A Choice Between Induced Draft and Forced Draft In Stationary Boiler Plants are principally as follows: Induced draft tends, at all times, to cause an inward flow of air through openings leading to the ashpits, furnaces and combustion chambers. It thus affords ventilation of the boiler room and offers

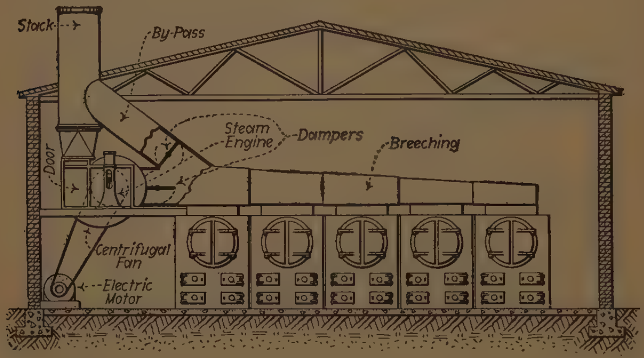


Fig. 486.—Wheel-fan blower installed between breeching and stack for induced draft.

no impediment to safe and comfortable manipulation of the fires. Forced draft tends, at all times, to blow fire, smoke and ashes out through the joints of furnace, combustion-chamber and ashpit doors, and through crevices in the boiler masonry. Thus it may cause befoulment of the

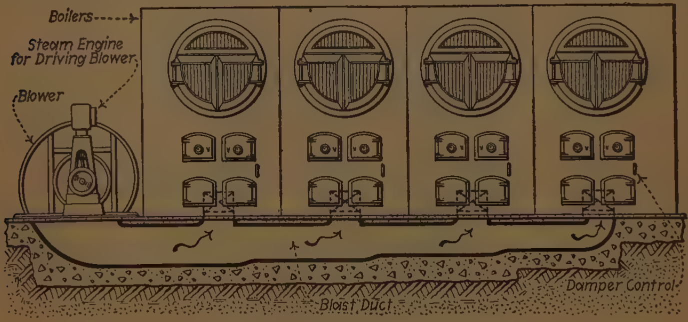


Fig. 487.—A forced draft-system for battery of boilers.

air in the boiler room. Also it prevents the withdrawal of ashes from the pits and the raking, cleaning or stoking of the fires while the blast is on. It tends to cause warping of the boiler fronts by overheating.

Induced draft is conducive to uniform intensity of the fire. Forced draft is apt to cause the fires to burn unevenly. Induced draft conduces

to economy of floor space by reason of the apparatus being installed overhead. Restricted head-room and unfavorable location of the breeching might make forced draft necessary where induced draft might otherwise

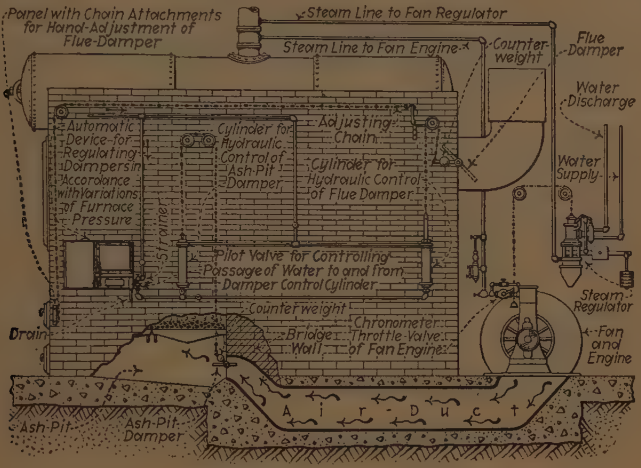


FIG. 488.—A balanced-draft system (The Engineer Co.).

be desirable. The installation of induced-draft fans in existing plants is usually difficult. Forced-draft apparatus is, particularly in the smaller capacities, comparatively easy to install. Induced draft tends to min-

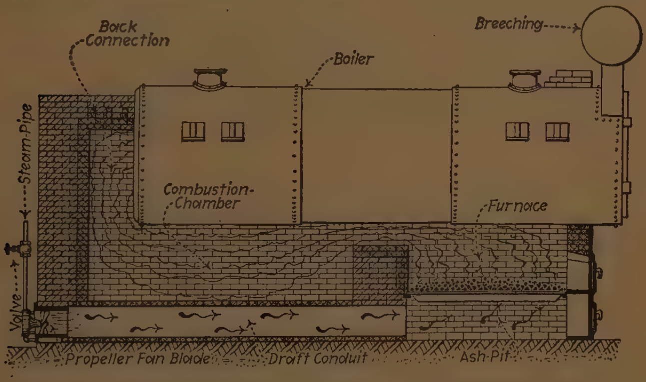


FIG. 489.—Forced draft produced with propeller-fan blower.

imize the accumulation of soot on the boiler surfaces. Forced draft necessitates extra precautions to keep the heating surfaces clean.

Induced draft, artificially produced, is advantageous where economizers are installed. It supplies the deficiency in the draft, naturally induced

by the chimney, which results from absorption, by the water in the economizer, of a portion of the heat in the flue gases. Forced draft is advantageous where underfeed stokers are employed. It possesses the force necessary to overcome the excessive resistance of very thick fuel beds. It is necessarily used with hollow blast grates. It operates to interrupt the formation of clinker and to penetrate beds of fuel which tend to pack on the grate, as where anthracite screenings are burned.

589. Balanced draft (Fig. 488) is a method of promoting combustion in a boiler furnace by means of a blending of forced draft with induced draft. A fan-blower creates a blast-pressure in the ashpit which is just sufficient to overcome the resistance of the fuel bed. The suction of the chimney, or of a mechanical device, induces a draft above the fuel bed. The forced and induced drafts are so adjusted automatically, by means of dampers and fan-controlling devices, that only sufficient velocity of flow to carry the gases in the direction of the chimney exists in the combustion chamber.

NOTE.—The purpose of balanced draft is to economize the process of combustion by obviating the necessity for admitting large quantities of excess air to the furnace.

590. Steam-jet blowers may have a steam consumption equal to 30 per cent. of the total quantity of steam generated. With some systems of forced-draft steam-blowers, the steam consumption may be as low as 2.5 per cent. The average range for such systems is from about 4 to 6 per cent.

NOTE.—The most extensive use of steam-jet blowers is in connection with portable and semi-portable steam-power outfits. Regardless of their draft-producing effect, steam jets are often introduced into ashpits in order to counteract the tendency of the ash, in certain grades of coal, to fuse and mat on the grate.

591. The maximum artificial draft which a steam-jet blower can produce is, for a forced-draft installation (Fig. 481), about 1 inch of water, and for an induced-draft installation (Figs. 479 and 480), about 0.75 inch. This refers to the excess of draft pressure over that which can be produced by the stack alone.

592. The steam consumption of a fan-blower for producing either induced- or forced-draft ranges from 2 to 4 per cent. of the steaming capacity of the plant.

NOTE.—Although forced draft operates under a higher pressure than induced, the volume displaced is smaller. This accounts for the same power consumption in both cases.

QUESTIONS ON DIVISION 21

1. When is artificial draft necessary? When is it desirable? When is it neither necessary nor desirable?

2. What is *forced draft? Induced draft?*

3. What considerations may ordinarily decide a choice between induced-draft and forced-draft whenever an artificial-draft system is to be installed?

4. In what respect is a balanced-draft system assumed to promote economy of combustion?

5. What is the average percentage of the steam consumption of steam-jet blowers? Of fan-blowers?

DIVISION 22

FUEL ECONOMIZERS

593. The function of an economizer (Fig. 490) is to absorb heat from the flue gases which are discharged from a boiler setting. The heat thus absorbed would otherwise be lost by passing out of the stack into the atmosphere. The economizer is more effective in absorbing this *waste heat* than would be

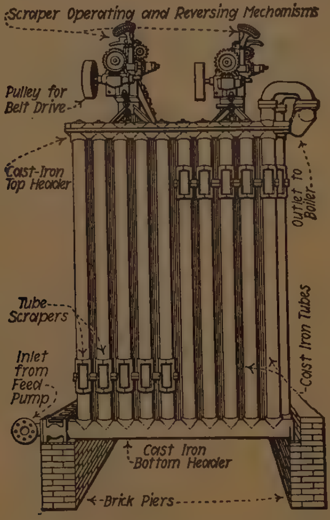


Fig. 490.—Sturdevant high-pressure type economizer.

additional boiler heating surface. This is because of the greater temperature difference which effects the heat transfer to the economizer; as shown in the example below. Economizers are treated in more detail in the author's Steam-Power-Plant Auxiliaries and Accessories.

Example.—With 150 lb. per sq. in. gage pressure the temperature of the steam is about 366 deg. Fahr. (Note that many steam-turbine plants

now operate at pressures of from 175 to 200 lb.) Hence, with a chimney-flue temperature of 500 deg., there is only 500 − 366 = 134 *deg.* temperature difference to effect heat transfer from the discharging flue gases to the additional boiler heating surface. On the other hand, the temperature of water entering an economizer is usually less than 200 deg. Thus, with an economizer, the temperature gradient which effects heat transfer is at least 500 − 200 = 300 *deg. Fahr.*

NOTE.—THE CONSTRUCTION, MAINTENANCE, OPERATION, ECONOMY AND FUNCTIONS OF THE ECONOMIZER are discussed more fully in the Author's STEAM POWER PLANT AUXILIARIES AND ACCESSORIES.

NOTE.—ORDINARILY IT DOES NOT PAY TO INSTALL ECONOMIZERS IN NON-CONDENSING PLANTS, because in such there is usually more than sufficient exhaust steam to heat the feed water. If the exhaust steam of a non-condensing plant can be utilized for industrial purposes, then economizer installation may be justified.

594. In locating an economizer it must always be in the flue-gas path between boiler and chimney. In general, the route

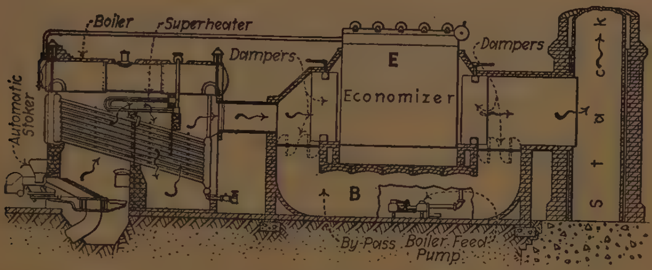


FIG. 491.—Green's fuel economizer (under by-pass) installed in connection with a water-tube boiler.

through the economizer should be as direct to the stack as is feasible so that the resistance to the flue-gas flow will be a minimum. Usually a *by-pass, B* (Fig. 491), is provided so that the hot gases may, when repair or inspection is necessary, be shunted around the economizer.

595. The placing of an economizer with respect to the boiler should be determined by: (1) *The type of boiler.* (2) *Whether head room or floor space is most available.* (3) *Whether the installation is in a new or in an old plant.* With boilers of certain types, the economizer may be located (Fig. 492) at practically the same general elevation as that of the boiler. With boilers of other types, the economizer is located most

effectively above (Fig. 493) the boiler. Where the economizer is installed overhead, considerable otherwise-unavailable floor

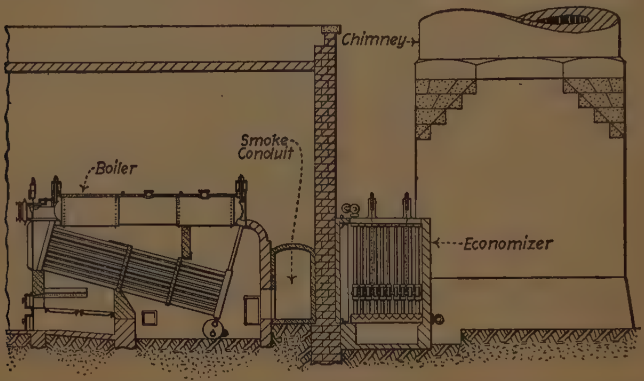


FIG. 492.—Economizer located out of doors on same floor level with boiler.

space may be rendered useful. In existing plants, where floor space is not available, but head room is, the economizer may be installed as suggested in Fig. 494.

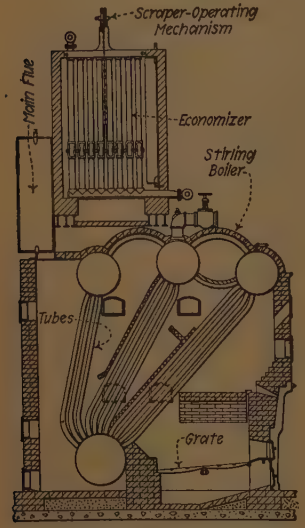


FIG. 493.—Economizers mounted above boiler.

596. The effect of an economizer on draft is, obviously, to decrease the draft pressure which is available (Sec. 486) at the chimney intake. The draft-pressure drop through an economizer is for normal operation, usually equivalent to about 0.10 in. to 0.20 in. water column. For operation at 200 per cent. boiler rating, it may be from 0.15 to 0.25 in. Cases have been recorded where the drop has been as great as 1.6 in. water column, with the boilers operating at about normal rating.

NOTE.—THE USE OF ECONOMIZERS FREQUENTLY NECESSITATES THE INSTALLATION OF MECHANICAL-DRAFT FAN (Fig. 494). This is partially to overcome the friction which the introduction of an economizer into the

flue-gas path involves. But it is principally to counteract the cooling effect of the economizer on the flue gases, which reduces materially the total draft pressure; see Sec. 479. But where the economizer is justified, the operation cost of the fan is, ordinarily, much more than offset by the saving due to the economizer.

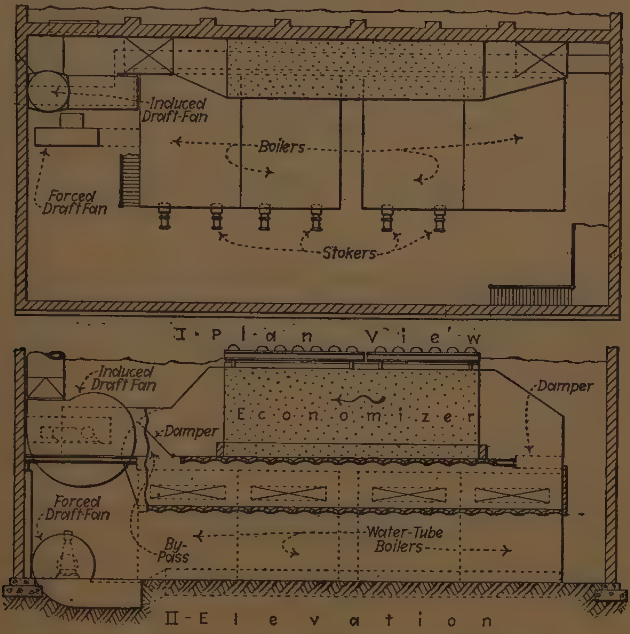


FIG. 494.—Sturdevant economizers located above boiler in an existing plant, where head room is available but floor space is not. This is an induced-draft, forced-draft installation.

QUESTIONS ON DIVISION 22

1. In what manner does an economizer improve boiler-room economies?
2. Would you install an economizer in a non-condensing plant? Why?
3. Why is a mechanical draft installed frequently in connection with economizers?
4. Why is an economizer more effective in absorbing waste heat than is additional boiler heating surface?
5. Discuss the general considerations which affect the location of an economizer in relation to the boiler.
6. What drop in draft pressure may ordinarily be expected through an economizer under normal conditions? Under overload conditions? What maximum drop has been recorded?

DIVISION 23

FEED-WATER AND FEED-WATER TREATMENT

597. Boiler feed-water from natural sources is never pure. It will always be found contaminated with other substances in solution or suspension. The impurities may be either solids or gases. If the former, they will be deposited in the boiler as the water evaporates into steam. If the latter, they will pass out with the steam.

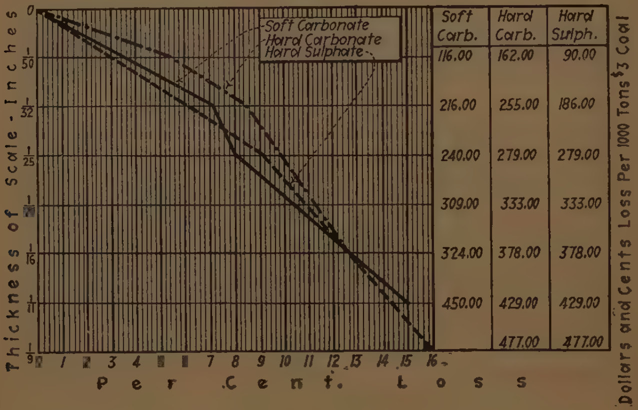


FIG. 495.—Graph showing monetary loss due to soluble impurities in boiler feed-water (compiled by F. F. Vater).

NOTE.—Pure feed-water is vital both to the economy of operation (Fig. 495) and to the durability of steam boilers.

598. The original or prime sources of feed-water supply for steam boilers may be broadly classified as follows: (1) *Cisterns of rainwater that may have drained from the roofs of buildings.* (2) *Lakes, streams and reservoirs of surface-water which may have drained from surrounding hills.* (3) *Springs and wells of ground water which may have percolated through earth and rock strata.*

NOTE.—*Rainwater* is invariably free from solid matter in solution. It may, however, be more or less contaminated with suspended impurities which are gathered from the air and from surfaces over which it flows. *Surface water* may, generally, be free from soluble or dissolved substances. It is, however, always contaminated more or less with animal and vegetable matter, and perhaps with acids. *Well or spring water* is rarely free from soluble mineral matter.

599. The effects of impure water as boiler-feed may be manifested in four different ways: (1) *By foaming and priming* (Sec. 396). (2) *By sludgy deposits on the water surfaces.* (3) *By incrustive or scaly deposits on the water surfaces.* (4) *By internal corrosion* (Secs. 633), *affecting both the water- and steam-surfaces.*

600. The impurities found in feed-water from natural sources may be approximately classified as follows: (1) *Sedimental or sludge-forming substances.* (2) *Incrustive or scale-forming substances.* (3) *Scum-forming substances.* (4) *Corrosive substances.*

NOTE.—*Sedimental or sludge-forming substances* in feed-water usually consist of mineral and organic particles which are suspended in the water. The mineral particles are formed of earthy or inert matter. The organic particles are formed of animal and vegetable matter. *Incrustive or scale-forming substances* consist principally of lime and magnesia which are temporarily dissolved in the water in the form of carbonates and sulphates. *Scum-forming substances* may be either mineral or organic. The mineral impurities may consist of soda in the form of a permanently soluble carbonate, sulphate, or chloride. The organic matter generally occurs in sewage-contaminated water. *Corrosive substances* may consist of chloride of magnesia, organic and mineral acids, carbonic acid in combination with oxygen, and grease.

NOTE.—Water that contains incrustive ingredients, in excess of about 10 grains per gal. is known as *hard water*. It is *temporarily hard water* if the incrustive ingredients, as the carbonates of lime and magnesia are precipitated at a temperature of about 212 deg. Fahr. It is *permanently hard water* if the incrustive ingredients (such as sulphate of lime) are precipitated at temperatures above 300 deg. Fahr.

NOTE.—INCRUSTATION OR SCALE IN STEAM BOILERS commonly betrays the presence of incrustive substances in the feed-water. Such scale is an accumulation of impurities, which adhere to the water surfaces of the boiler in the form of a crust. It occurs in varying degrees of density and hardness. The scale-forming tendency of the incrustive substances may often be supplemented by that of sedimental substances. If the sludge, which is formed by sedimental deposits, lodges on the heating

surfaces, it may unite with the incrustive precipitates and become baked to a hard, rigid scale.

NOTE.—THE MOST SERIOUS DIFFICULTY WHICH ATTENDS THE PRESENCE OF SCUM-FORMING SUBSTANCES IN BOILER WATER is the foaming and priming (Sec. 396) which is likely to result. *Foaming* or an inordinately violent ebullition of the water may occur where animal or vegetable oils in the feed-water become saponified by the action of soda ash and thus form a sudsy scum. *Priming*, or a geyser-like action of the water, may result from the formation (by an accumulation of flocculent mineral matter in conjunction with organic matter) of a heavy glutinous skin on the surface of the water.

601. The process by which soluble incrustive substances are precipitated from boiler water to form scale may, according to the nature of the substances, occur in either of two ways: (1) *By the water losing, at the prevailing temperature, its power to hold the temporarily dissolved substances in solution.* (2) *By crystallization of the permanently soluble substances through the excessive concentration which may result from continuous evaporation of the water.*

NOTE.—Lime and magnesia in the form of carbonates are precipitated at a temperature of about 212 deg. Fahr. When in the sulphate form, they remain dissolved until the water is heated to about 300 deg. Fahr.

NOTE.—THE EXTENT TO WHICH CONCENTRATION OF PERMANENTLY SOLUBLE IMPURITIES IN WATER IN A BOILER MAY PROCEED with safety, varies according to the nature of the impurities and the conditions of operation. It may range from 30 to 300 grains per gal. Excessive concentration will generally be revealed by priming. This will usually occur before the concentration has reached the limit of saturation, or the degree wherein scale-formation occurs. A concentration, per gal., of 175 grains of chloride of soda or 300 grains of carbonate of soda may cause no difficulty. Concentration beyond these limits may be troublesome. Where concentration is excessively rapid, a correspondingly-frequent blowing down may be necessary. But this might entail a cumulative loss of heat energy which, from the viewpoint of economy, would render use of the water prohibitive.

602. The characteristics of boiler scale vary according to the nature of the substance which forms the scale. The carbonates of lime and magnesia usually produce a soft, porous, scale which is more or less penetrable by water. Sulphate of lime produces an extremely hard and dense scale which is impervious to water. Sulphate of magnesia alone produces a comparatively soft scale. But if both sulphate of

magnesia and carbonate of lime are present, there ensues a chemical reaction which reduces the precipitates to hydrate of magnesia and sulphate of lime. These combine to form a particularly hard and flinty scale.

NOTE.—Carbonate of magnesia may precipitate as a light, flocculent, scum-forming substance. If it encounters much grease while in this form, the two impurities may combine to produce a spongy scale which is exceptionally troublesome on account of its extremely high resistance to heat transfer.

603. Three general methods are available for coping with impurities in boiler feed-water: (1) *The boiler may be opened periodically and the precipitated impurities scraped and washed out.* (2) *Substances may be injected into the boiler along with the feed water, in order to minimize or obviate, by chemical or mechanical processes, deleterious action by the impurities.* This is *after-treatment* of the water. (3) *The acids may be neutralized and the solids eliminated before the water is fed to the boiler.* This is *pretreatment* of the water.

NOTE.—Unless the water contains none but non-corrosive, sedimental impurities, and these in very moderate quantities, the first method enumerated in the preceding Sec. should not, in any case, be relied upon exclusively. The second method, or after-treatment, should be attempted only by prescription of a competent chemist. The third method, or pretreatment, is advantageous in any case. As a matter of economy, its use is generally imperative where the impurities are present in large quantities and are of complicated variety.

604. Three general chemical processes of pretreatment of boiler water are available for scale-prevention: (1) *The lime process.* (2) *The soda process.* (3) *The lime-and-soda process* (Figs. 497 and 498).

NOTE.—THE DESIRABILITY OF ARTIFICIAL PURIFICATION OF NATURAL WATERS WHICH ARE INTENDED FOR BOILER-FEED may be considered from two points of view:

(1) *The relative impurity of the water.* (2) *The expense of purification as compared with the expense due to the physical depreciation, the labor of cleaning, and the diminished evaporative efficiency of scaled, corroded and sediment-containing boilers.* Natural waters sufficiently pure for boiler-feed are common in many localities. The impurities may be such that their deposits can be expelled from the boilers, practically as fast as formed with blow-off apparatus. In these cases the boilers may be safely and

profitably continued in service for periods extending from a few weeks to several months without being opened for cleaning. In other localities the untreated water available for boiler-feed may be so loaded with impurities that the boilers can be run only two or three days between cleaning. The treatment necessary for purification should always be prescribed by a chemical expert.

605. The lime process of pretreatment of boiler water is used where the principal incrustive substances are the carbonates of lime and magnesia. It is applied by introducing a quantity of lime water, which is a solution of slaked lime (hydroxide of lime).

NOTE.—The carbonates of lime and magnesia are, normally, present in combinations with carbonic acid. The compounds thus formed are the bicarbonates of lime and magnesia. These are soluble in water. The added limewater draws a portion of the carbonic acid from the bicarbonates and combines therewith. This union produces carbonate of lime, which is insoluble in water. But the bicarbonates, having been deprived of a portion of the carbonic acid which held them soluble, are also reduced to insoluble carbonates. Thus the impurities are caused to precipitate in the purifying apparatus one as carbonate of lime and the other as carbonate of magnesia.

606. The soda process of pretreatment of boiler water is used where the sulphates of lime and magnesia are the principal incrustive ingredients. It is applied by introducing either soda ash, (carbonate of soda) or caustic soda (hydroxide of soda). In some cases these chemicals are used together.

NOTE.—When soda ash is added to feed-water which contains the sulphates of lime and magnesia, but which is virtually free from carbonic acid, it reacts directly with the sulphates. Carbonates of lime and magnesia and sulphate of soda are thus produced. The lime and magnesia precipitate in the purifying apparatus. The soda remains in solution. But soda in the form of a sulphate is harmless if it is not permitted to concentrate (Sec. 608) to an excessive degree. This may be prevented by periodic blowing down.

If carbonic acid is present, it will combine with the carbonates of lime and magnesia which result from the decomposition of the sulphates. Soluble bicarbonates will thus be formed. The carbonic acid may, however, be expelled by preheating the water (Fig. 496) above 190 deg. Fahr.

The chemical reactions with soda ash proceed very slowly at ordinary atmospheric temperatures. Speedier action may be realized by using caustic soda instead. But, in the absence of carbonic acid, the precipi-

tations will be incomplete. The soda will react directly with the magnesia in the sulphate and thus form hydroxide of magnesia. This, being insoluble, will precipitate in the settling tank. The caustic soda will also react with the lime in the sulphate form and so produce hydroxide of lime. But this is very soluble. Hence no precipitation will occur. If, however, sufficient carbonic acid is present, the hydroxide of lime will react therewith to form insoluble carbonate of lime. In this case the precipitations will be complete.

607. The lime-and-soda process of pre-treatment of boiler water is used where the water contains an excess of carbonic acid in addition to the sulphates of lime and magnesia. It is applied by introducing enough caustic soda to decompose the sulphates, and enough slaked lime to form insoluble monocarbonate of lime by union with the portion of the carbonic acid which is not absorbed in the soda reactions. The lime reactions will counteract any tendency for the development of soluble bicarbonates.

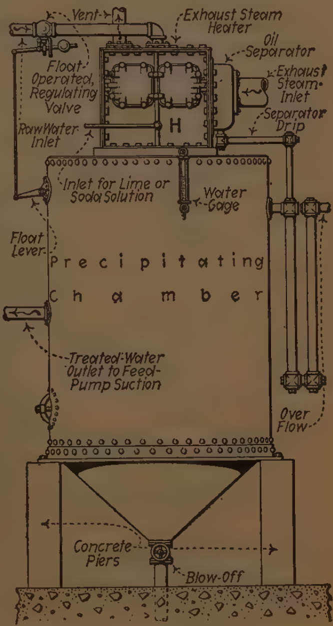


Fig. 496.—Apparatus for pretreatment of hot raw water with lime and soda (Sorge-Cochrane system).

608. The allowable concentration of soda in pretreated boiler water is between 25 and 70 grains per gal. Trouble may ensue if the concentration is outside these limits, either above or below.

Note.—Where pretreated water is fed to all the boilers in a plant a sample of water from each boiler should be tested chemically once a week to determine the soda content. If the test shows less than about 25 grains per gal., the deficiency may be supplied by pumping in the necessary quantity of a saturated solution of soda. If the upper limit of concentration is exceeded, the soda content may be reduced by blowing down.

609. Pretreatment for removal of sedimental and scum-forming substances (Sec. 600) may be either mechanical or

chemical. Mechanical treatment consists in extracting the suspended mineral and organic matter by filtration (Fig. 497). Chemical treatment consists in clarifying the water with alum in the form of a sulphate. There is no practical way of extracting the various soda solutions. Their tendency to cause priming can be abated only by keeping a constant check on their degrees of concentration. (Sec. 608.)

NOTE.—Alum acts to precipitate suspended impurities by coagulation. But this will occur only when the water contains alkalis. Therefore, if neither lime nor magnesia are naturally present, alkaline must be supplied by the addition of caustic soda or soda ash.

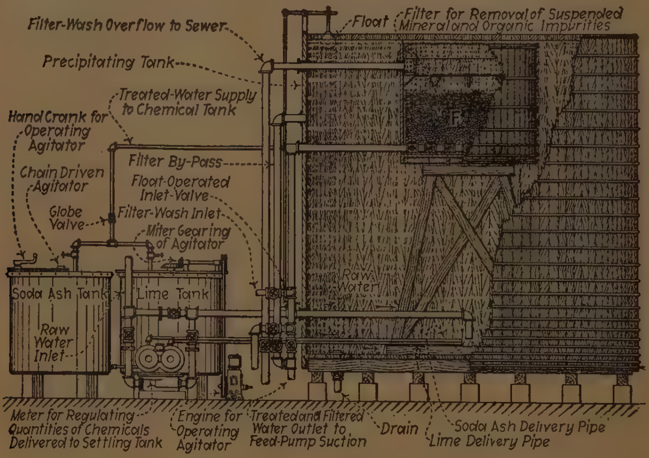


FIG. 497.—Apparatus for pretreatment of cold raw water with lime and soda (the water system).

610. Pretreatment for counteracting the destructive effects of corrosive substances in feed-water involves both mechanical and chemical processes. When the corrosive substances consist of oils, and other organic matter which distil acids, their removal may be effected (Fig. 497) by filtration. The corrosive effect of oxygen may be obviated by expelling the air from the water. This may be done (Fig. 496) by preheating. Other corrosive elements respond only to chemical pretreatment.

NOTE.—Mineral acids rarely occur in appreciable quantities in waters from natural sources. When present, however, they may be neutralized readily by the lime which is used in the processes of pretreatment for

incrustive impurities. The corrosive property of chloride of magnesia is eliminated by precipitation of the magnesia in the soda process of pretreatment. Dissolved carbonic acid is also neutralized in the lime-and-soda process.

611. The cost of operating a lime- and soda-purifying apparatus embraces two principal items: (1) *The cost of labor.* (2) *The Cost of chemicals.* In addition there are *fixed charges* on apparatus, including: interest on investment, depreciation, taxes, insurance and maintenance.

NOTE.—The cost of labor may be computed approximately as about 1 cent per 1000 gal. of water pretreated. Where the impurities are mainly lime and magnesia in the form of carbonates and sulphates, the cost of the materials might be computed as approximately 5 cents per 1000 gal. This estimate is based on the assumption that the water contains about 30 grains of scale-forming matter per gal., and that the market price of lime is 50 cents, and of soda ash, 1 dollar per 100 pounds.

612. Boiler compounds or scale solvents generally contain soda and tannin. In some cases they contain vegetable ingredients which are presumed to envelope the particles of incrustive substances with a film or skin which prevents their adherence to the metal surfaces. *Graphite* is also presumed to have this effect.

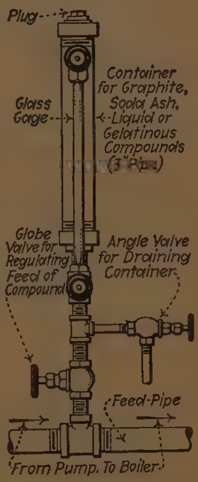


FIG. 498.—Apparatus for feeding scale solvents and preventives.

NOTE.—The purpose of soda in boiler compounds is to reduce the hard scale to a sludgy mass. The purpose of tannin is to penetrate between the scale and the boiler metal. The soda is employed to reduce the scale to a form in which it may be readily blown out. The tannin is intended to simplify removal of the scale when the boiler is opened for cleaning. If the use of a scale solvent is necessaary, it should be introduced in small quantities at frequent intervals through an apparatus (Fig. 498) which may be attached to the feed pipe.

613. Crude oil and kerosene as scale preventives are comparatively ineffective. Serious trouble may attend their use as such.

QUESTIONS ON DIVISION 23

1. What becomes of gaseous impurities in feed-water?
2. What are the most conspicuous evidences of impure feed-water?
3. How is sediment formed in a boiler?
4. How is scum formed?
5. In what state or condition do incrustive substances dwell in feed-water?
6. What is *temporarily-hard water?* *Permanently hard water?*
7. What are the principal *incrustive ingredients* in boiler water?
8. What is *boiler scale*?
9. What are the principal corrosion impurities in feed waters?
10. How may sludgy sedimental deposits develop into scale formations?
11. What phenomena mainly indicate the presence of scum on the surface of boiler water?
12. What is the nature of the scum that ordinarily causes *foaming?* That causes *priming?*
13. By which natural processes does precipitation of incrustive impurities in boiler water occur?
14. What is the safe maximum degree of concentration of soluble or dissolved impurities in boiler water?
15. How may excessive concentration be prevented?
16. What is the chief physical characteristic of the scale which is formed by the carbonates of lime and magnesia? Of scale which is formed by the sulphates of lime and magnesia?
17. What three distinct procedures are available for coping with the impurities in feed-waters?
18. Upon what considerations does the desirability of artificial purification of feed-water mainly rest?
19. Describe the *lime process of purification. The soda process. The lime-and-soda process.*
20. What are the active principles of boiler compounds?
21. What are prime sources of feed-water supply?
22. What sort of impurities may be found in rain water? In surface water? In spring water?

DIVISION 24

MANAGEMENT, INSPECTION AND MAINTENANCE OF STEAM BOILERS

614. Management of a boiler embraces such activities as are necessary to continuous and efficient operation. These activities are directed mainly as follows: (1) *To insure, at all times, a full supply of the best quality of feed-water obtainable.* (2) *To provide an adequate supply of fuel and to burn it economically.* (3) *To furnish a continuous supply of steam, at a constant pressure, for all of the purposes for which the plant is designed.*

615. Inspection of boilers comprises such activities as are necessary to the acquisition of precise knowledge regarding the physical condition of all parts of the boilers and their accessories.

NOTE.—Inspection of the furnaces, settings and chimneys of boiler plants is correlated with inspection of the boilers themselves.

616. The maintenance of a boiler comprises certain duties which are necessary to preservation of the working efficiencies of the boiler and its appurtenances. The appurtenances include furnaces, settings, chimneys and other accessory apparatus. The duties of maintenance tend to conserve both economy and safety.

617. Control of the feed-water supply should receive vigilant attention. The water should be fed to the boiler continuously. With constant load the quantity flowing in should be as nearly equal as practicable to the quantity going out in the form of steam. By observing this rule, the highest feed-water temperature possible with the available heating apparatus is fully realized. Likewise, a continuous supply of steam, as dry as the structural limitations of the boiler will permit, is assured.

618. Dangerously low water in a boiler is an emergency wherein a portion of the heating surface is without the protection of water-contact. It occurs rarely under proper management. Nevertheless it is a condition that should be anticipated.

NOTE.—When the water becomes dangerously low the boiler should be cooled as quickly and as safely as possible. If the feeding apparatus is already working, it should be allowed to continue. Otherwise it should not be started. Neither should it be speeded up. Usually, the fire may be most conveniently smothered by covering it with wet ashes. All doors and passages through which cooling currents of air may pass, to the combustion chamber, should be opened. When it is certain that no water is being evaporated, the fire may be drawn and the boiler emptied. The boiler should not be continued in service until the condition of the exposed surface has been determined by competent inspection. If the boiler is fitted with fusible plugs, the ends of the plugs should be kept free from insulating deposits of soot and scale. This is vital to their prompt action (Fig. 499) in the event of dangerously low water.

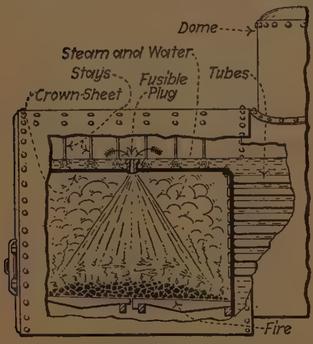


FIG. 499.—Fusible plug giving notice of low water in a horizontal fire-box boiler.

619. Economy of Boiler Operation is Mainly a Matter of Skillful Firing.—Efficient hand-firing is in evidence when the fires are kept at an even thickness, when holes are not permitted to burn in the fuel bed, and when ash and clinker are as carefully removed from the sides and corners of the furnace as from the middle surfaces. The depth of the fire should be adjusted in accordance with the demand for steam. The draft should be so controlled that it will produce the most economical percentage of CO_2. (See Div. 15, COMBUSTION AND FIRING.) The cleaning of the fires should be attended to systematically.

NOTE.—When ash and clinker have accumulated to the extent of darkening the ashpit, cleaning of the furnace should not be delayed.

620. Proper Use should be Made of the Blowoff Apparatus.—In the average boiler plant, which uses ordinary feed-water,

one of the effects of evaporation is a constantly augmented concentration of the impurities in the boilers. This may be avoided by blowing down frequently. Formation of scale may also be diminished by frequent use of the blowoff apparatus. All mineral matter held in suspension in the feed-water tends, when the water is heated to a boiling temperature, either to fall to the bottom plates or to rise to the surface. By frequent blowing, both from the surface and from the bottom, much of the suspended matter, which might otherwise settle on the plates and form scale, is ejected.

NOTE.—In a test of a few day's duration without blowing off, the foreign matter in the water in a boiler increased from 25 grains to 750 grains to the gallon. It required but a comparatively short time, when the water was not changed by blowing off, to produce a solution containing over 1000 grains to the gallon. There is a marked difference in the quantity of heat absorbed under this condition, which is unfavorable alike to efficiency and longevity of the boiler.

NOTE.—Most of the suspended solid matter in boiler water is precipitated as a loose sediment. Scaly deposits, on the other hand, are usually due to mineral matter which is held in solution.

621. The proper time for blowing scum and sediment from a boiler is when the water is quiescent. This occurs in the intervals when there is practically no outflow of steam, as at noontime in a manufacturing plant, or early in the morning, before the plant is in operation. Blowing off while the water is quiescent insures that the sediment and scum-forming substances have had time to so accumulate as to be carried out with the currents of water issuing through the blowoff piping.

622. The proper procedure in handling the bottom blowoff values when blowing out an accumulation of sediment is this: First, open the *auxiliary valve* or cock *C* (Fig. 500). Then open the *blowoff valve V*. When the water level has been blown down to a depth of about 2 or 3 in., close *V*. Then close *C*. Now *V* should again be opened for a short interval to permit the water in it to drain out, after which it should be closed finally.

NOTE.—TWO BLOWOFF VALVES (*C* and *V*, Fig. 500), CONNECTED IN SERIES, ARE SPECIFIED for power boilers by the A.S.M.E. CODE.

One valve provides insurance against failure of the other. In practice, the *blowoff valve*, *V*, is specially designed to withstand the excessive wear-and-tear of blowoff service. This wear is caused by the rushing currents of sediment-charged water. The *auxiliary valve* *C* may be a relatively low-priced and simple cock. By operating the valves in the sequence specified above, the erosion, due to wire drawing when the valve is almost closed, is imposed on the specially-designed valve, *V*.

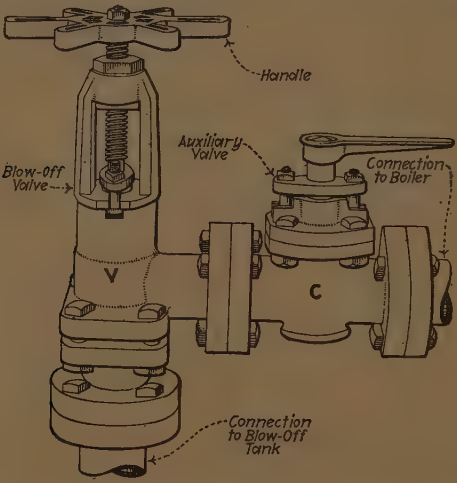


FIG. 500.—Proper arrangement of blow-off valves.

NOTE.—EXPERIENCE DICTATES THAT THE COCK *C* SHOULD BE PLACED NEXT TO THE BOILER. Valve *V* should be outside. Then, when the boiler is being washed out, the bonnet or center piece may be removed from *C*, permitting the wash water to flow directly from the boiler to the sewer. Meanwhile, *V* is permitted to remain closed, so that steam from the blow-off lines can not pass it and injure a man who may be working in the boiler.

NOTE.—A LEAKING BLOW-OFF IS A SOURCE OF SERIOUS LOSS. It has been computed that, when a boiler carries a working pressure of 150 lb. per sq. in., 36,000 gallons of water will be wasted in a month's time through a leak in the blow-off corresponding to a circular orifice 0.0625 in. in diameter. With coal having a heating value of 13,000 B.t.u. per pound, and costing $3.00 per ton, and water metered at the rate of 10 cents per 1000 gal., the loss due to lost water and lost heat would amount to over $12.00 per month of boiler operation.

623. Blowing down the water column is vital to the safety of the boiler and to the durability of the water-column con-

nections. The quiescent condition of the water in the column invites clogging of the connections by mud-forming impurities in the water. The column should in any case, be thoroughly blown down at least twice a day. Where the water is more than ordinarily impure, more frequent blowing, perhaps as often as four or five times on a watch, might be necessary.

624. The condition of the top and the bottom connections of the glass water gage is indicated by the behavior of the water when returning to the normal height in the glass after the glass has been blown out.

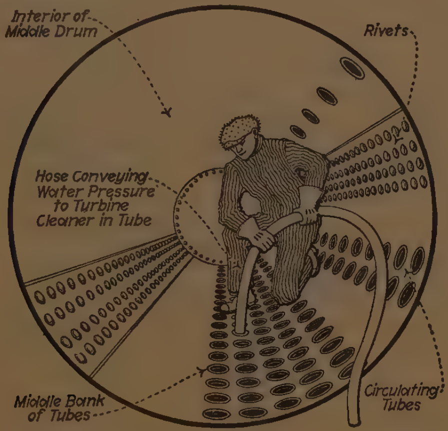


FIG. 501.—Cleaning the tubes of a Stirling boiler.

NOTE.—If the water rushes instantly to the top of the glass, and then recedes slowly to the normal level, it is a sure sign of a restricted steam passage. If the water travels and settles slowly and deliberately, up the glass and settles quietly at a plane coincident with the true level, then an obstruction undoubtedly restricts the water passage. But if the water shoots up the glass with high velocity, its momentum carrying it a little above the regular stage, at which it settles after a few rapid fluctuations, the action indicates perfect freedom in both passages.

625. The care exercised in cleaning a boiler (Fig. 501) largely affects its safety and economy. The quality of the feed-water mainly determines the interval that should elapse between successive internal cleanings. The kind of fuel and the quantity burned are the principal factors in regulating the periods of external cleaning. However, it is, in any case,

essential to economy that soot deposits be blown (See Div. 11 for SOOT BLOWERS) from the tubes at least once a day. When the boiler is laid up for internal cleaning, all manhole and handhole plates should be removed so as to provide maximum accessibility to all parts.

626. Cleaning the interior of a new boiler, before the boiler is placed in service, is very necessary. The plates of a boiler acquire a coating of oil while they are being assembled. Foaming will inevitably result if this is permitted to remain. The interior surface may be cleaned by scouring it with an alkaline solution.

NOTE.—A quantity of soda ash should be placed in the boiler. The boiler should be filled with water to the top gage cock. A fire should be started and maintained slowly for about 12 hours. The boiler should then be allowed to cool slowly. When the water has become tepid, the boiler should be emptied and washed out. The soda ash dissolved in the simmering water will have cut the greasy coating from the plates and tubes. Therefore, the grease will readily pass out with the water. About 1 lb. of soda ash should be used for each 15 cu. ft. or 940 lb. or 110 gal. of water which is put into the boiler.

627. Cutting a boiler into the line consists in opening the connection between the boiler and the main header or steam

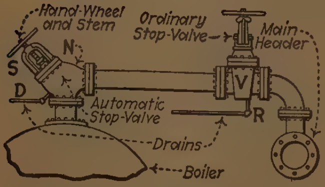


FIG. 502.—Steam connection equipped with automatic and ordinary stop valves.

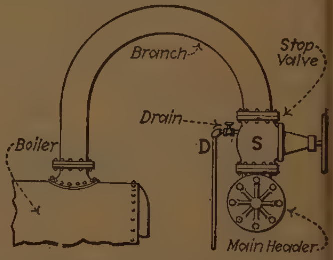


FIG. 503.—Steam connection equipped with single ordinary stop valve.

line. It is the operation of placing the boiler in service. In a boiler plant composed of two or more units, this operation usually occurs while other boilers are already delivering steam to the main header. It may then be done automatically if the boiler is equipped (Fig. 502) with an automatic non-return stop valve. Otherwise (Fig. 503) it must be done by manipulation of an ordinary stop valve.

NOTE.—When a fire is started under a boiler which is equipped (Fig. 503) with an automatic non-return stop valve N, the operator should first see that the drains, D and R, are open. He should next open slowly the stop valve, V, and close the drains, D and R. He may then screw the stem, S, of the non-return valve, N, out to the wide-open position. Until the steam in the boiler attains the same pressure as that in the main header, the disc of the non-return valve will be seated by the force of its own weight alone. The disc will, therefore, rise automatically from its seat in response to a further very slight increment of pressure per sq. in. in the boiler.

When a fire is started under a boiler which is unprovided (Fig. 503) with an automatic non-return stop valve, the operator should see that the drain, D, is open. When steam begins to blow strongly through it, D, should be closed. When the pressure in the boiler becomes equal to the pressure in the main header, the stop valve, S, should be opened very cautiously for about two turns. It may then be opened up rapidly. Extreme care should be taken to guard against opening the stop valve, S, before the pressures have become equalized, or to delay its opening until the boiler pressure exceeds the header pressure. Proper performance of this duty mainly depends upon the accuracy of the steam gages on the boilers.

628. A boiler-room log (Fig. 504) is indispensable in maintaining a proper standard of operating efficiency. It is also a valuable guide when plans for improvement are being devised. It should exhibit a record of all important data pertaining to the condition and operation of the boiler plant.

NOTE.—The basis of an adequate system of records in a boiler plant is the daily log, a weekly summary of which is suggested in Fig. 504. The average values which are given in the summary are presumed to be the daily averages of values which have been read hourly on the indicating instruments and recorded in the daily log.

When a boiler plant is equipped with a recording thermometer in the feed-water line, a recording pyrometer in the chimney connection, a recording draft gage, a recording steam gage, and a recording flue-gas analyzer, the charted records which are taken from the instruments afford, in themselves, a connected history of the plant's performance.

For descriptions of steam-power-plant recording instruments, see the Author's PRACTICAL BOILER-ROOM ECONOMY and his PRACTICAL HEAT.

629. Inspections of Boilers should be made Systematically.—At intervals of at least three months, each boiler in a plant should be examined critically by the engineer in charge. The sheets and seams should be investigated for evidences of

distortion, fractures and corrosion. The braces and stays should be tested to determine their soundness. The search for defects should also include every detail of the accessory apparatus and of the furnace and setting.

SUMMARY OF DAILY BOILER-ROOM LOG FOR WEEK ENDING Nov. 15 '19

DAY	BOILER NO. 1					BOILER NO. 2					BOILER NO. 3					BOILER NO. 4					AVERAGE FLUE TEMPERATURE DEGREES FAHR.	AV. FEEDWATER TEMPERATURE DEGREES FAHR.	ASHES REMOVED POUNDS
	COAL BURNED, POUNDS	WATER EVAPORATED POUNDS	AV. STEAM PRESSURE LB. PER SQ. IN.	AVERAGE DRAFT, INCHES	AVERAGE CO_2, PER CENT.	COAL BURNED, POUNDS	WATER EVAPORATED POUNDS	AV. STEAM PRESSURE, LB. PER SQ. IN.	AVERAGE DRAFT, INCHES	AVERAGE CO_2, PER CENT.	COAL BURNED, POUNDS	WATER EVAPORATED POUNDS	AV. STEAM PRESSURE, LB. PER SQ. IN.	AVERAGE DRAFT, INCHES	AVERAGE CO_2, PER CENT.	COAL BURNED, POUNDS	WATER EVAPORATED POUNDS	AV. STEAM PRESSURE LB. PER SQ. IN.	AVERAGE DRAFT, INCHES	AVERAGE CO_2, PER CENT.			
SUN	21050	225400	150	0.7	11.0						540	4900	—	—	—	490	3700	—	—	—	310	210	1800
MON	19600	19570	150	0.72	10.5	Out					20500	185900	150	0.72	9.5	21600	22200	150	0.72	11.5	330	208	5500
TUES	18400	180600	150	0.7	11.0			of					150	0.7	9.5	21500	216000	150	0.7	11.5	320	207	5100
WED	21700	201000	150	0.69	11.5				Service				150	0.69	10.0	14600	140000	150	0.69	10.0	310	210	4400
THUR	20600	207100	150	0.7	10.00								150	0.7	10.5	16000	151000	150	0.7	10.0	340	209	4300
FRI	18950	174300	150	0.71	9.5								150	0.71	11.0	20100	210000	150	0.71	9.5	310	209	5600
SAT	19870	199100	150	0.71	10.0								150	0.71	11.0	15100	156000	150	0.71	10.0	315	210	4100

RECORD OF CLEANINGS AND REPAIRS OF BOILERS, FURNACES AND ACCESSORIES

BOILER NO. 1	Glass water gage renewed.
BOILER NO. 2	Drums washed out and tubes turbined. Two defective tubes (4th and 8th in bottom row) replaced with new ones. Outer blow off valve ground in. Inner blow-off valve repacked. Fusible plugs renewed.
BOILER NO. 3	Diaphragm of damper regulator renewed.
BOILER NO. 4	Disc of feedwater regulating valve renewed.

RECORD OF CONDITION OF BOILERS, FURNACES AND ACCESSORIES

BOILER NO. 1	Furnace arch needs renewal.
BOILER NO. 2	Placed in serviceable condition during week.
BOILER NO. 3	Check valve leaks. Automatic stop valve needs overhauling.
BOILER NO. 4	Safety valve leaking slightly. Head of one stay bolt in rear water leg needs calking.

REMARKS

No. 3 and 4 boilers banked from 2:00 A.M. Sunday to 3:00 A.M. Monday.
Quality of coal delivered during week was very irregular.
Base of chimney needs cleaning.
(SIGNED) William Jones
CHIEF ENGINEER

Fig. 504.—Suggested record form for boiler-room use.

630. Tests for the discovery of defects in a boiler are as follows: (1) *The hammer-test.* (2) *The hydrostatic test.* A hammer-test consists in tapping all parts of the boiler with light hammer blows. The condition of a part so tested is revealed both by the sound which is emitted and by the quality of the

vibration which is set up in the fiber of the metal. The vibration is noted by applying the finger tips to the metal close to where the hammer blow is being struck. A hydrostatic test consists in filling the boiler with water, attaching a small specially-designed hand-pump (Fig. 505) to a convenient opening in the boiler, and then pumping up a hydraulic pressure about 50 per cent. greater than the steam pressure which the boiler is required to carry, See A.S.M.E. BOILER CODE.

NOTE.—The hammer test should always be used to determine the condition of a boiler. The hydrostatic test alone is not to be relied upon for revealing dangerous conditions. Hydraulic pressure is valuable chiefly in determining the tightness of joints and riveted seams.

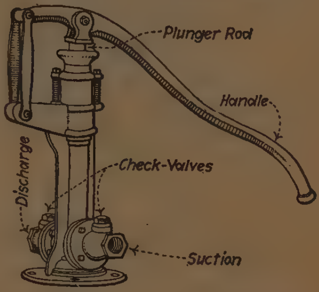


FIG. 505.—A hydrostatic test pump (Walworth Mfg. Co.).

631. Evidences of corrosion on the plates and seams of a boiler should be looked for constantly and diligently. They may be found both externally and internally.

632. External corrosion of boiler surfaces is generally produced by leaks through riveted seams and by drippings from the joints of piping and other fittings. When moisture spreads between the sheets of a boiler and the surrounding brickwork it cannot escape readily by evaporation. Corrosion of the metal will, therefore, result. Moist ashes in contact with the boiler metal is also a common cause of external corrosion. The sulphur in the coal distils, during combustion, an acid gas. Deposits of soot in the passages through the boiler will absorb this gas. If the gas-saturated soot becomes moistened by water from a leak, or other source, the gas will be converted to sulphuric acid. This is particularly ruinous to boiler metal.

633. Corrosion of the interior surfaces of boilers may be manifested as follows: (1) *By uniform wasting of the plates and rivets.* (2) *By pitting or honey-combing* (Fig. 506). (3) *By grooving or channelling* (Figs. 507, 508, 509 510, and 511. In all cases, the principal cause is the same. This, stated

generally, is chemical reaction between the boiler metal and an acidulated and air-impregnated body of water. Internal corrosion may also be due, occasionally, to galvanic action.

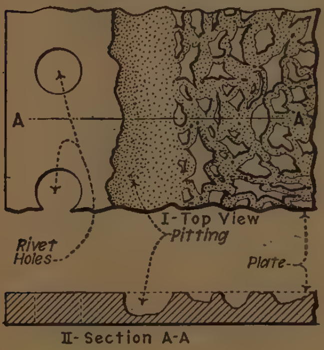


FIG. 506.—Pitting of a boiler plate.

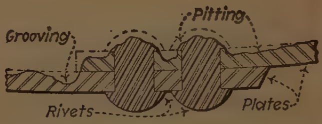


FIG. 507.—Grooving of plate and pitting of plate and rivets.

634. Uniform wasting of boiler metal may be difficult to detect. It is a very insidious form of corrosion. This is due to the evenness of its progress throughout very extended areas of the plate. The hammer test will generally reveal its pres-

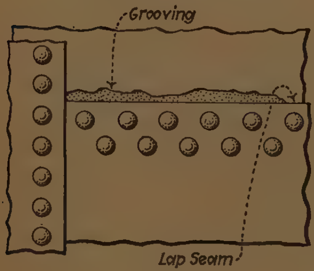


FIG. 508.—Grooving at edge of lapped plate.

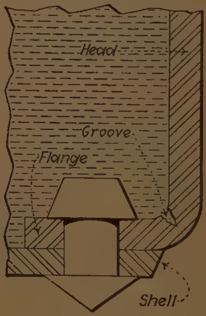


FIG. 509.—Groove corroded in fillet of head flange.

ence to the skilled boiler inspector. If any doubt should exist as to its progress, a 0.5-in. hole should be drilled in the suspected area so that the plate-thickness may be calipered. The hole may then be threaded and plugged.

635. Pitting or honey-combing (Fig. 506) may, as a rule, be observed readily. It appears as more or less extended aggregations of irregularly-shaped depressions in the metal. It may be found in all parts of the interior surface of a boiler, sometimes above but usually below the water-line. The pittings are frequently found filled with a powdered substance composed of iron and mineral and organic matter precipitated from the water.

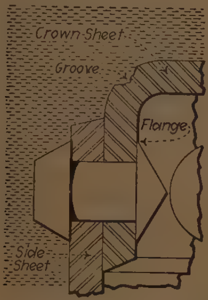


FIG. 510.—Groove corroded in outer curve of flange of crown sheet in horizontal fire-box boiler.

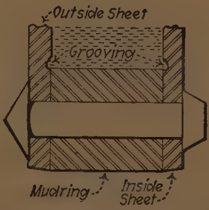


FIG. 511.—Grooves corroded, at edges of mud-ring, in sheets of horizontal fire-box boiler.

636. Grooving, or channelling, usually occurs along the edges of lapped seams (Fig. 507 and 508), the rounded corners of flanges (Fig. 509 and 510), the edges of mud-rings (511), and similar locations. It is often difficult to detect. It may originate due to inherent local rigidity of a certain part of the boiler metal which prevents the part from conforming readily to alterations in form induced by expansion and contraction. This resistance of a part of the metal to change of shape causes the adjacent metal to bend a correspondingly greater amount. The increased bending of the adjacent metal may be sufficient to continually disrupt formations of scale or rust along a narrow length of its surface. Thus, a strip of clean metal is being constantly exposed to the attack of the acids in the water and the subsequent corrosion. Grooving is the result. The *breathing* action of a boiler, which is due to variations of pressure, may bend parts of the shell sufficiently to cause grooving.

637. When operation of a boiler plant is to be discontinued for an extended period, special precautions should be adopted to guard against deterioration. The boilers should be cleaned thoroughly, both internally and externally. All deposits of soot and ash should be scraped, brushed and blown from the plates and tubes. Scale should be removed from the interior surfaces. The tube-ends and riveted joints should be examined for leaks. All defective joints should be repaired. The surfaces, both inside and outside, should then be so treated as to ward off corrosion.

NOTE.—CORROSION IN BOILERS WHICH ARE OUT OF SERVICE may be prevented in several ways. If the period of idleness is to be less than about 3 months, the boilers may be kept full of water. About 1 lb. of soda ash for each 15 cu. ft. of space should be dumped into the water in each boiler. Slow fires should be started. The water should be heated to a steaming temperature in order to expel the air from the boilers. The fires should then be drawn and the boilers pumped full.

If suspension of service is to continue longer than about 3 months, the boilers should be emptied, cleaned and dried thoroughly. The surfaces, both inside and outside, may then be coated with crude mineral oil. Or, crude oil may be used on the inner surfaces and boiled linseed oil on the outer. Linseed oil will form a more durable coating than will crude oil. Otherwise, the exterior surfaces may be painted with either red lead or tar. Portions of the exterior surface which are beyond convenient reach may be given a protective coating by the burning of tar beneath them. The tar thus volatilized will float upward to the otherwise inaccessible surfaces and cling thereto.

A film of crude oil may be spread upon the interior surfaces by filling each boiler with water, adding about 10 gallons of the oil, and then opening the blow-off valves. As the water level descends, the floating oil will adhere to the plates and tubes. A boiler so treated must be purged with soda ash (Sec. 626) before it is again placed in service. If pitting is noted in the drums of water tube boilers, a coat of zinc paint should be applied.

The smoke stacks and chimneys of idle boiler-plants should be covered with water-tight hoods.

QUESTIONS ON DIVISION 24

1. What activities in a boiler plant fall within the meaning of the word *management*? Of the word *inspection*? Of the word *maintenance*?
2. What visible criterion of proper control of the feed-water supply is most apparent?
3. What benefits are realized by close regulation of the feed to a boiler?
4. What is the proper course of action in a low-water emergency?
5. What are the visible evidences of skilful firing?
6. What benefits result from proper use of the blow-off facilities?

7. When is the best time to blow down a boiler? Why?

8. In what order should the two valves in a blow-off connection be opened and closed? Why?

9. When the glass water-gage is blown down, what symptoms indicate the condition of the passages in the connections?

10. What considerations should determine the frequency of the internal cleanings of a boiler?

11. How may a new boiler be purged?

12. What manipulation is necessary for cutting in a boiler which is furnished with an automatic non-return stop valve?

13. What should be the procedure in cutting in a boiler? Why?

14. What is the fundamental reason for maintaining a boiler-room log?

15. What is a hammer test? A hydrostatic test?

16. Why is damp soot a prolific source of corrosive activity?

17. How may the depth of penetration of uniform wasting in a boiler plate be known exactly?

18. In what parts of a boiler does pitting occur?

19. What is the cause of grooving?

20. How should a boiler be laid up for a temporary period? For a prolonged period?

DIVISION 25

SELECTION OF STEAM BOILERS

638. The Selection Of Steam Boilers is a subject which naturally classifies into two divisions: (1) *Selection as to type.* (2) *Selection as to size* or *rating.* So many different factors affect the situation that it is possible to submit only general suggestions. Each project should be considered individually and treated on its merits in accordance with the methods recited hereinafter.

639. Some Factors Which Should Be Considered When Selecting The Type Of Boiler For A Given Service are as follows: (1) *Character Of Load,* whether steady or varying, duration and magnitude of peaks, plains and valleys in the load graph; load factor. (2) *Space Available For Installation.* (3) *Labor Available For Operation.* (4) *Can Boiler Be Shut Down for Cleaning?* (5) *Feed Water Available.* (6) *Draft Pressure Which Is Available.* (7) *Will Or Will Not Mechanical Stokers Be Used?* (8) *Efficiency Of Boiler.* (9) *Kinds Of Fuel Available.* (10) *Initial And Maintenance Costs.*

640. The Determination Of The Most Economical Type Of Boiler For A Given Installation Can Not Be Based On Any Single Feature.—On the contrary, all possible factors should be given consideration. The problem usually resolves itself into one of determining what type of boiler or boilers will generate, under the conditions obtaining in the plant in question, a pound of steam for the least money. Or, assuming that the same amount of steam will be generated in a year by each of the different tentative boiler installations, the problem is then one of determining which of the installations will have the least annual cost. Only the general method of procedure will be outlined. The detail process will vary for different cases.

EXPLANATION.—First, determine the total first costs of complete installations of boilers of the different types which are under considera-

641. Table Showing Method Of Determining The Annual Cost Of Steam-Boiler Operation

	Item	How computed	Total costs
Fixed Charges	Depreciation =	Amount laid aside yearly to replace unit when it is worn out. Based on first cost and life of equipment. Ranges from 20 % of first cost each year for a 5 yr. life to 4 % for a 25 year life =	*D*
	Interest =	Cost of interest per year on the money which is invested in the boiler installation. Figure at prevailing rate. Usually 6 % or 7 % of first cost, per year =	*I*
	Insurance =	Yearly cost of insuring the installation against fire, explosion, etc. Figure at prevailing rate usually about 0.75 % of first cost, per year =	*N*
	Taxes =	Yearly cost of taxes on the installation. Figure at prevailing rate, usually about 0.75 % of first cost =	*T*
	Rent	Rental cost yearly of floor space occupied by boiler.	*R*
Operating Expense	Coal	Cost of the coal burned in a year.	*C*
	Coal Handling	Yearly cost of labor and other expense incurred in handling the coal after it reaches the plant.	*H*
	Firing	Yearly cost of firing the coal.	*F*
	Maintenance	Yearly cost of repairs, labor and material necessary to maintain plant in operating condition.	*M*
Total annual cost, $A = D + I + N + T + R + C + H + F + M =$			*A*

tion. Each of the different installations should be designed to generate the same number of pounds of steam per year which is required by the project. The first costs of the different tentative installations having been thus determined, ascertain the total annual cost for each. The *annual cost*, A, will (Table 641) be the sum of the items $D + I + N + T + R + C + H + F + M$. The installation which has the least annual cost will be the most economical.

642. The Selection Of A Return-Tubular Vs. A Water-Tube Boiler may usually be determined on this basis: For unit capacities between say 75 and 150 to 175 b.h.p., a return-tubular boiler is usually, everything considered more economical than a water-tube boiler. While the water-tube boiler may be somewhat more efficient when operated under ideal conditions, its higher first cost, in the smaller capacities, per boiler horsepower ordinarily, where these smaller capacities are concerned, more than offsets the possible increase in economy that may occur through its use. Not only do the small water-tube boilers themselves cost more per boiler horsepower than do the return-tubular, but they also cost more to install. The cost per boiler horsepower of small water-tube boilers is much greater than the cost per boiler horsepower of the large ones. In fact, for the reasons just outlined, water-tube boilers are seldom manufactured in capacities smaller than 175 b.h.p. On the other hand, return tubular boilers are seldom made in capacities greater than 175 b.h.p. because if so made they would be altogether too bulky for practical and economical handling. Hence, where the boiler units are larger than about 175 b.h.p., some type of water-tube boiler will ordinarily be the most economical.

NOTE.—MECHANICAL STOKERS ON RETURN-TUBULAR BOILERS are not, in general, economical. This is largely because the capacities in which return-tubular boilers are made are not ordinarily great enough to justify the automatic stoker operation. For large boiler units, automatic mechanical stokers pay. For small ones they do not.

643. In Selecting The Preferable Type Of Water-Tube Boiler for a given set of conditions, the factors cited in Secs. 639 and 641 and possibly others should be given consideration. In general, all of the different makes and designs of water-tube boilers which are made by reputable manufacturers will, when

operated at their rated capacities, show practically the same economies. Some are, however, more expensive to maintain than others. Again, some respond more readily to forcing for overloads than do others. Furthermore some may operate more economically at certain overloads than do others. Reliable information as to comparative maintenance costs is difficult to obtain and must usually be based on one's personal experience or on the personal experiences of one's acquaintances. The boiler manufacturers can usually give efficiency guarantees for normal and overload operation.

The Baffling Of Water-Tube Boilers has considerable influence on their economics, particularly when they are operated at over loads. Horizontally-inclined water-tube boilers may be either: (1) *Vertically baffled*, Fig. 514. (2) *Horizontally baffled.* Which type of baffling is preferable is at this time (January, 1921) undecided. In general, the vertically-baffled appears to be the more economical and to effectively carry greater overloads than the horizontally-baffled.

Note.—When Installing A Water-Tube Boiler be sure that there is sufficient space in front or rear of the boiler to permit renewal of the tubes or flues.

644. The Applications For Which Vertical Water-Tube Boilers Should Be Selected are those in which the floor space occupied must be a minimum. In general they are not as economical nor can they be operated at high overloads as can inclined-tube water-tube boilers. They require a high boiler room. The maintenance of their tubes may be difficult. They have been employed effectively for waste-heat utilization in steel mills.

645. Of The Water-Tube Boilers, One Of The Sectional Type Should Be Selected When The Installation Space Is Restricted.—Thus, a boiler of the sectional type, such as the Babcock & Wilcox, has the advantage that its components can be passed through relatively-small openings in the plant building. The pieces can usually be taken through an ordinary door. Furthermore such a boiler may be readily designed as to be high-and-narrow or low-and-wide to fit the available space. On the other hand "built-up" boilers require relatively large openings for their passage, and ordinarily, they are not made in sizes which are readily adaptable to either high-and-narrow or low-and-wide spaces.

646. In Selecting A Boiler Which Will Be Subjected To Heavy Overloads, on which it should operate with high economy, a water-tube boiler should be chosen which: (1) *Presents to the combustion gases the maximum surface for heat transfer.* (2) *Has large steam-liberating surface.* (3) *Has unrestricted water circulation.* See note below.

Example.—The Edgemoor boiler (Figs. 512, 513 and 514) is an example of a type which will carry heavy overloads with good economy when equipped with a properly-designed furnace. One feature of this design which enables it to respond readily to overloads is (Fig. 512) the absence of restricted throat areas. Similarly, the steam paths in this boiler, from the heating surfaces

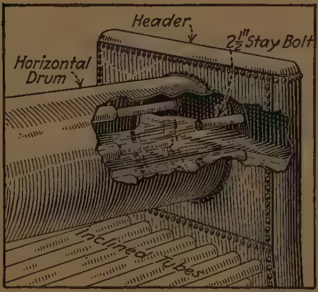


Fig. 512.—Unrestricted connection between header and drum.

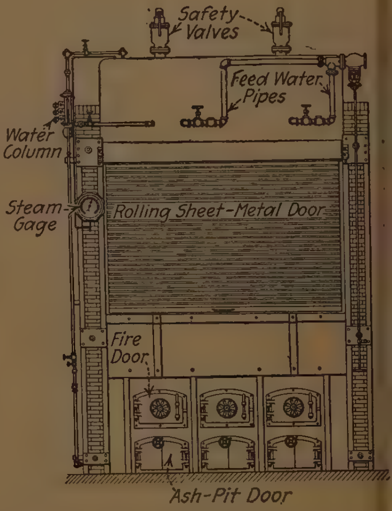


Fig. 513.—Edgemoor boiler front.

where the steam is generated to the steam space, offer but little restriction. In practice, properly-designed water-tube boilers have been found to respond readily to heavy overloads. They will, with good economy carry continuously overloads equivalent to 200 per cent. of rated capacity (100 per cent. overload). They will carry periodical peaks, such as those which occur in electric-central-station practice, equivalent to 300 per cent. of rated capacity (200 per cent. overload). The most economical load appears to be about 175 per cent. of rated capacity (75 per cent. overload) and in practice many boilers may effectively be operated continuously at this load.

Note.—It should be understood that, primarily, its furnace design will determine the overload capacity of any boiler-and-furnace unit.

647. In Selecting A Water-Tube Boiler, Consideration Should Be Given To The Draft Pressure Which Is Available In The Plant.—If the draft pressure which is produced by the existing stack is low and it is necessary to utilize this stack unmodified, then care should be exercised to select a boiler of such type that the existing draft pressure will be sufficient for its operation. Usually a return-tubular boiler can be operated by a stack which would not operate an equivalent water-tube boiler.

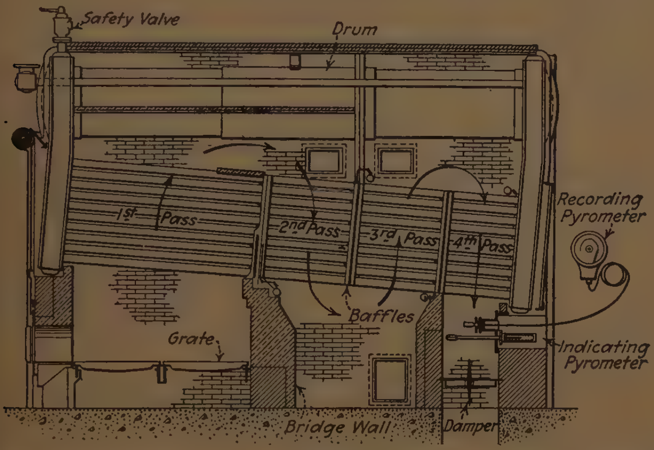


FIG. 514.—Four-pass vertically baffled Edgemoor boiler equipped with soot blower and with recording and indicating pyrometers to study effects of soot blowing.

648. The Suitable Applications For The Vertical-Fire-Tube Boilers (see Secs. 63 to 68 for description) are those which require a small-capacity, simple, self-contained, low-first-cost unit. The features just listed are about the only ones in favor of boilers of this type. The vertical fire-tube boilers are uneconomical; in fact, it is impossible to design coal-fired boilers, of the small sizes in which these are made, which will have both low first-cost and high economy. Vertical-fire-tube boilers have economies of possibly only 50 to 70 per cent. of those of return-tubular boilers: The vertical-fire-tube boilers will evaporate about 4 lb. of water per lb. of coal as against about 6 lb. of water per lb. of coal for the

return-tubular boilers. Vertical-fire-tube boilers may be purchased in capacities of from 5 to, say, 75 b.h.p.

NOTE.—SINCE THE VERTICAL FIRE-TUBE BOILERS ARE ABOUT THE ONLY SELF-CONTAINED SMALL-CAPACITY UNITS OBTAINABLE AT REASONABLE COST, they are widely used for hoisting-engines and tractors, and in cleaning and dying establishments, restaurants and bakeries, where in the steam is used direct in the industrial processes. In many localities it is legal to operate such boilers (provided a specified steam pressure is not exceeded) without a licensed engineer.

649. The Proper Policy To Pursue In Taking Advantage Of The Overload Capacity Of Boilers should be governed by conditions. In small plants where there is only one or a few boilers and where the load is steady, it is well to assume in selecting the boiler sizes that the boilers have no overload capacity. That is, the installed boilers should be of sufficient size that they will, when rated on the conventional basis of each 10 sq. ft. of heating surface generating 30 lb. of steam per hour, supply the steam requirements of the plant. Then, the overload capacity which lies latent in each boiler will be available for emergencies. Poor coal, poor firing and accidents are some of the elements which may necessitate the utilization of the latent overload capacity.

But in electric-power-and-lighting and street-railway boiler plants and in all others where there are periodical peaks—it is usually well to recognize the guaranteed overload capacity of the boilers and to utilize it in handling the peaks. These peaks are ordinarily of relatively-short duration (see graphs in the author's CENTRAL STATIONS). In large plants where there are a number of boilers it is probably always good engineering to recognize, and utilize conservatively, the overload capacity.

NOTE.—IT SHOULD BE UNDERSTOOD THAT OVERLOAD CAPACITY OF A BOILER ULTIMATELY REVERTS TO A PROBLEM OF PROPER FURNACE AND STOKER DESIGN. With an improperly-designed furnace and an illogically-selected stoker, even the very best boiler could not be made to carry overloads economically.

650. In Selecting The Sizes Of Boilers For An Installation where the aggregate rated capacity of the boiler plant is less than, say, 1,500 b.h.p., but not excessively small, the following

general method may, under certain conditions, be followed: *Estimate the maximum total load to be imposed on all of the boilers together and then select three boiler units, all of equal size, which together will, at normal rating, carry somewhat more than this total load. That is: each unit should have a normal rating of somewhat more than ⅓ of the total load.* With this arrangement (one boiler being out of service) the two remaining boilers, by working at an overload which they will handle, can carry the plant. In certain cases, it may be desirable to divide the total load between four instead of between three units.

EXAMPLE.—Assume that the total load to be imposed on a boiler plant is equivalent to 450 *b.h.p.* Then 450 ÷ 3 = 150 *b.h.p.* Now if three 160 *b.h.p.* boilers are selected, two of them will have a combined capacity of 160 + 160 = 320 *b.h.p.* Hence, with two of them carrying the total load, the overload would be 130 ÷ 320 = 40.6 *per cent.* The boilers could, with a properly-designed furnace, handle this overload effectively and economically.

651. When Determining Boiler Capacities For A Plant Upon Which The Imposed Load Is Unsteady, First Plot A Load Graph using *pounds of steam per hour* for ordinates and *hours of the day* as abscissæ. (Examples of load graphs for loads of different characteristics are reproduced in the author's CENTRAL STATIONS.) Such a graph will assist one in visualizing conditions and be of great service in selecting capacities such that the normal loads and overloads can be handled effectively.

652. Some General Rules Which May Usually Be Followed In Selecting Boiler Sizes are these:

1. All boilers in a plant should preferably be of the same size and type to insure interchangeability of parts and uniformity of equipment and operating methods.
2. The sizes should be so selected that, if possible, such boilers as are working in the plant should always be working at or near their most economical loads.
3. In general, return-tubular boilers should not, for economic reasons, be larger than 175 nor smaller than say 75 *b.h.p.*; see Sec. 642.
4. Water-tube boilers should not (see sec. 642) in general, for economic reasons, be smaller than about 175 *h.p.* They may be as large as 1,000 rated *b.h.p.* or even larger if necessary.

NOTE.—WHERE A BOILER PLANT WILL OPERATE 24 HR. DAILY, 7 DAYS EACH WEEK, IT IS IMPERATIVE THAT AT LEAST TWO BOILER UNITS BE INSTALLED so that one of them may be shut down for cleaning while the other is being operated. But where the plant is small and can be shut down on Sundays, then, in certain cases, one boiler unit may suffice.

653. Boiler Sizes In Large Central Stations, Which Are Practically Always Designed In Accordance With The Panel System, should be so selected that maximum-economy requirements will be satisfied. In the panel system, each turbo-generator and the boilers which supply it constitute a unit. Usually, each such boiler-turbo-generator unit when operating, operates at full load. Thereby, maximum economy is obtained. The number of boilers in each panel unit should be such that when they are all working they will carry the total load economically and should be such that each individual boiler will be of proper size to afford ready installation and repair and an effective furnace and complete design.

QUESTIONS ON DIVISION 25

1. Into what two classifications may the selection of steam boilers be divided?
2. Name the chief factors which should be considered in selecting the type of boiler for a given service.
3. Outline the general method of procedure in determining the most economical type of boiler.
4. Upon what basis may the selection of a return-tubular vs. a water-tube boiler usually be determined?
5. What effect is produced upon water-tube boilers by baffling?
6. For what conditions of installations are vertical water-tube boilers usually selected?
7. What characteristics should a water-tube boiler have if it is to be subjected to heavy overloads?
8. In what way may the overload capacity of boilers be utilized?
9. Explain the method of procedure which may be employed in determining boiler capacities for a varying-load plant.
10. Give four general rules which may be followed in selecting boiler sizes.
11. What is the *panel system* of boiler design? What are the advantages of such a system?

APPENDIX

SOLUTIONS TO PROBLEMS

The Following Solutions To The Problems, which have been presented at the ends of the various Divisions throughout the book, are included to assist the student. These solutions should be referred to only after the reader has made an earnest effort to solve, without assistance, the problem which is under consideration. If used in this way, these solutions may constitute a material aid. But if the reader refers to this appendix before he has made an honest effort to work out his own solution, then, the material in this appendix will, probably, do more harm than good.

The Same Symbols And The Same Formulas Are Used in these solutions as those which are employed in the Division which precedes the problems which are proposed in the text portions of the book.

SOLUTIONS TO PROBLEMS ON DIVISION 6

STRESSES IN AND STRENGTHS OF STEAM BOILERS

1. $P_T = dLP_{gt} = (4 \times 12) \times (20 \times 12) \times 125 = 1{,}440{,}000$ *lb.*

2. $d = (P_T)/(LP_{gt}) = 1{,}152{,}000 \div [(24 \times 12) \times 120] = 1{,}152{,}000 \div 34{,}560 = 33.3$ *in.*

3. $P_T = rLP_{gt} = 21 \times (40 \times 12) \times 90 = 907{,}200$ *lb.*

4. $S_{Tt} = (2L_tU_tL)/f = 2 \times 0.375 \times 54{,}000 \times (20 \times 12) \div 5 = 1{,}944{,}000$ *lb.*

5. $P_{gt} = (2L_tU_t)/(df) = (2 \times 0.25 \times 45{,}000) \div (36 \times 4.5) = 2{,}500 \div 18 = 139$ *lb. per sq. in.*

6. $P_L = 0.7854d^2P_{gl} = 0.7854 \times 21^2 \times 150 = 51{,}954$ *lb.*

7. $S_{tl} = (3.14dL_tU_t)/f = (3.14 \times 21 \times 0.3125 \times 50{,}000) \div 5 = 206{,}060$ *lb.*

8. $P_{gl} = (4L_tU_t)/(df) = (4 \times 0.3125 \times 50{,}000) \div (21 \times 5) = (0.3125 \times 40{,}000) \div 21 = 12{,}500 \div 21 = 595$ *lb. per sq. in.*

9. *One-half of round-about* $= 595 \div 2 = 297.5$ *lb. per sq. in.*

10. $P_{gl} = (4L_tU_t)/(df) = (4 \times 0.125 \times 45{,}000) \div (15 \times 5) = 0.500 \times 600 = 300$ *lb. per sq. in.*

11. $P_{MAW} = (TS \times t \times E)/(R \times FS) = (50{,}000 \times 0.375 \times 0.80) \div (18 \times 5) = 3{,}000 \div 18 = 166.7$ *lb. per sq. in.*

12. $t = (P_{MAW} \times R \times FS)/(TS \times E) = (200 \times 18 \times 5) \div (50{,}000 \times 0.80) = 18 \div 40 = 0.45$ *in. or a little over* $\frac{7}{16}$ *in.*

SOLUTIONS TO PROBLEMS ON DIVISION 7

RIVETED JOINTS

1. *Strength of unit strip:* $S_T = L_U L_t S_T = 2\frac{1}{2} \times \frac{5}{16} \times 55{,}000 = 42{,}969$ *lb.*

Strength of riveted unit strip: $S_T' = (L_U - d)L_t S_t = (2\frac{1}{2} - \frac{3}{4}) \times \frac{5}{16} \times 55{,}000 = 30{,}078$ *lb.*

Strength of rivets in shear: $S_s = NAS_s = 2 \times 0.442 \times 44{,}000 = 38{,}896$ *lb.*

Strength of plate against crushing: $S_C = NdL_tS_g = 2 \times \frac{3}{4} \times \frac{5}{16} \times 95{,}000 = 44{,}531$ *lb.*

Least strength: $S_T' = 30{,}078$ *lb.*

Therefore, efficiency $= \dfrac{S_T'}{S_T} = \dfrac{30{,}078}{42{,}969} = 0.70 = 70$ *per cent.*

SOLUTIONS TO PROBLEMS ON DIVISION 11

BOILER ACCESSORIES

The area of the disc $= 3^2 \times 0.7854 = 7.07$ *sq. in.*

1. $P_B = \dfrac{W_W L_W + W_L L_L + W_D L_D}{A L_D}$. Solving for L_W:

$$L_W = \frac{A L_D P_B - (W_L L_L + W_D L_D)}{W_W}$$

$$= \frac{7.07 \times 2.5 \times 75 - (6 \times 15 + 1.5 \times 2.5)}{48} = 25.7 \text{ in.}$$

2. *The average absolute pressure of the steam* during each period of discharge $= \dfrac{120 + 116}{2} + 14.7 = 132.7$ *lb. per sq. in.* The *total duration of discharge* $= \dfrac{40 \times 4.5}{60} = 3$ *hr.* From formula in Table 302: *Loss per hour* $= W = 105\,LDP = 105 \times 132.7 \times 3.5 \times 0.1 = 4{,}877$ *lb.* *Total loss* $= 4{,}877 \times 3 = 14{,}631$ *lb.*

3. *The area of the disc* $= (3)^2 \times 0.7854 = 7.07$ *sq. in.*

$$P_B = \frac{W_W L_W + W_L L_L + W_D L_D}{A L_D}. \text{ Solving for } W_W:$$

$$W_W = \frac{A L_D P_B - (W_L L_L + W_D L_D)}{L_W}$$

$$= \frac{7.07 \times 2.5 \times 80 - (6 \times 15 + 1.5 \times 2.5)}{36} = 36.7 \text{ lb.}$$

SOLUTIONS TO PROBLEMS ON DIVISION 13

BOILER CAPACITIES AND RATINGS

1. The heating surface of the tubes = [(*oustide diam. in in.* − 2 × *thickness in in.*) × 3.1416 × *length of boiler in ft.* × *number of tubes*] ÷ 12 = [(3.5 − 2 × 0.12) × 3.14 × 16 × 40] ÷ 12 = 546 *sq. ft.* The heating surface of the shell (Sec. 407) = (3/8 × *diam. in in.* × 3.1416 × *length in ft.*) ÷ 12 = (0.375 × 52 × 3.14 × 16) ÷ 12 = 82 *sq. ft.* The total heating surface = 546 + 82 = 628 *sq. ft.* The nominal h.p. = 628 ÷ 10 = 62.8 *h.p.*

SOLUTIONS TO PROBLEMS ON DIVISION 19

DRAFT AND ITS PRODUCTION AND MEASUREMENT

1. $$P'_D = 0.52 L_h P_2 \left(\frac{1}{T_o + 460} - \frac{1}{T_G + 460}\right)$$

$$P'_D = 0.52 \times 110 \times 14.7 \times \left(\frac{1}{65 + 460} - \frac{1}{550 + 460}\right)$$

$$P'_D = 840.8 \times \left(\frac{1}{525} - \frac{1}{1010}\right) = 840.8 \times (0.001{,}905 - 0.000{,}990)$$

$$= 840.8 \times 0.000{,}915 = 0.765$$

$P'_D = 0.77$ *in. water column* = *total draft pressure.*

2. $$L_h = \frac{P'_D}{0.52 P_2 \left(\frac{1}{T_o + 460} - \frac{1}{T_G + 460}\right)}$$

$$L_h = \frac{2}{0.52 \times 13 \times \left(\frac{1}{55 + 460} - \frac{1}{500 + 460}\right)}$$

$$L_h = \frac{\text{[illegible]}}{6.76 \times \left(\frac{1}{515} - \frac{1}{960}\right)}$$

$$L_h = \frac{2}{6.76 \times (0.001{,}943 - 0.001{,}042)} = \frac{2}{6.76 \times 0.000{,}901}$$

$L_h = \dfrac{2}{0.00609} = 328$ *ft.* = *height of chimney.*

3. *Available Draft Pres.* = (*Elevation Draft Pres.*) − (*Fire and Vel. Drop*).
Available Draft Pres. = 0.47 − 0.09.
Available Draft Pres. = 0.38 *in. water column.*

4. $P''_D = 1.25(A.D.P.D._{BC})$.
$P''_D = 1.25 \times 0.75$.
$P''_D = 0.94$ *in. water column* = *total draft pressure.*

5. $A = \dfrac{W_c}{12\sqrt{L_h}}$

$$A = \frac{1.5 \times 2{,}000}{12\sqrt{120}} = \frac{3{,}000}{12 \times 10.9} = \frac{3{,}000}{131.5}$$

$A = 22.8$ *sq. ft.* = *area of flue.*

6. *Coal burnt per hr.* $= 4 \times 8 \times 500 \times 1.25 = 20{,}000$ *lb.*

Total grate area $= 83 \times 8 = 664$ *sq. ft.*

Pounds coal burnt per sq. ft. of grate surface per hr. $= \dfrac{20{,}000}{664} = 30.12.$

Hence (from Fig. 390) for Illinois bituminous coal, the available draft required for furnace and fuel bed is.......... 0.34 in. water column

Draft required for breeching (see Table 485 for values) is 50×0.001 =...................... 0.05 in. water column

Draft required for breeching elbows (see Table 485) is 2×0.05 =........................... 0.10 in. water column

Draft required for passes, assumed (Table 485) to be.................................... 0.40 in. water column

Total available or effective draft required = $A.D.P.D._{BC}$............................... 0.89 in. water column

Now, to find the total draft pressure which the chimney must develop from the smoke-conduit connection up, substitute in For. (68):

$$P''_D = 1.25(A.D.P.D._{BC}) = 1.25 \times 0.89 = 1.11 \textit{ in. water column.}$$

Then to find the height of stack required to develop $P''_D = 1.11$ in. water column, substitute in For. (66):

$$L_h = \frac{P_d'}{0.52P_2\left(\dfrac{1}{T_o + 460} - \dfrac{1}{T_G + 460}\right)} = \frac{1.11}{0.52 \times 13.57 \times \left(\dfrac{1}{60 + 460} - \dfrac{1}{550 + 460}\right)}$$

$$L_h = \frac{1.11}{7.05 \times \left(\dfrac{1}{520} - \dfrac{1}{1{,}010}\right)} = \frac{1.11}{7.05 \times (0.001{,}925 - 0.000{,}990)}$$

$$L_h = \frac{1.11}{7.05 \times 0.000{,}935} = \frac{1.11}{0.006{,}59}$$

$L_h = 168$ *ft.* = *height of chimney above smoke conduit connection.*

The flue area of the chimney should, For. (73), be:

$$A = \frac{W_c}{12\sqrt{L_h}} = \frac{20{,}000}{12\sqrt{168}} = \frac{20{,}000}{12 \times 12.98} = \frac{20{,}000}{156} =$$

$A = 128$ *sq. ft.* = *flue area*

The flue diameter should, For. (79), be:

$$d = \sqrt{\frac{W_c}{9.43\sqrt{L_h}}} = \sqrt{\frac{20{,}000}{9.43\sqrt{168.5}}} = \sqrt{\frac{20{,}000}{9.43 \times 12.9}}$$

$$d = \sqrt{\frac{20{,}000}{121.8}} = \sqrt{164.5}$$

$d = 12.8$ *ft.* = 12 *ft.* 10 *in.* = *chimney diameter.*

SOLUTIONS TO PROBLEMS ON DIVISION 20

CHIMNEYS, BREECHINGS, AND DAMPERS

1. $P = kv^2 = 0.003 \times 80^2 = 19.2$, *lb. per sq. ft.*
and: $P = kv^2 = 0.0035 \times 80^2 = 22.4$ *lb. per sq. ft.*

2. $F = \dfrac{L_{wb} + L_{wt}}{2} L_h P = \dfrac{9.5 + 8}{2} 120 \times 30 = 31{,}500$ *lb.*

3. $L_{hc} = \dfrac{L_{wb} + 2L_{wt}}{L_{wt} + L_{wt}} \times \dfrac{L_b}{3} = \dfrac{9.5 + (2 \times 8)}{9.5 + 8} \times \dfrac{120}{3} = 58.3$ *ft.*

4. $p''_c = \dfrac{FL_{hc}}{I \div c} = \dfrac{FL_{hc}}{0.118L^3} = \dfrac{25{,}000 \times (52 \times 12)}{(16 \times 12)^3 \times 0.118} = 18.74$ *lb. per sq. in.*

5. $p'_c = \dfrac{W}{A} = \dfrac{300 \times 2{,}000}{(16 \times 12)^2} = 16.3$ *lb. per sq. in. or* 1.17 *tons per sq. ft.*

$p_c = p'_c + p''_c = 18.74 + 16.3 = 35.04$ *lb. per sq. in. or* 2.52 *tons per sq. ft.*

6. $x = F \dfrac{L_{hc}}{W_i} = 30{,}000 \dfrac{45 \times 12}{600{,}000} = 27$ *in.*

7. $p'_c = \dfrac{W}{0.7854(d_o^2 - d_i^2)} = \dfrac{485 \times 2{,}000}{0.7854[(11 \times 12)^2 - (8\frac{1}{2} \times 12)^2]} =$ 176.5 *lb. per sq. in.*

8. $p''_c = \dfrac{FL_h}{I \div c} = \dfrac{FL_h}{0.7854[(r_o^4 - r_i^4) \div r_o]} =$
$\dfrac{40{,}000 \times (60 \times 12)}{0.7854[(5\frac{1}{2} \times 12)^4 - (4\frac{1}{4} \times 12)^4] \div (5\frac{1}{2} \times 12)} = 199$ *lb. per sq. in.*

9. $p_c = p'_c + p''_c = 176.5 + 198.5 = 375.0$ *lb. per sq. in.*

10. $P = kv^2 = 0.003 \times 95^2 = 27.075$ *lb. per sq. in.*
$F = A \times P = 11 \times 175 \times 27.075 = 52{,}119$ *lb.*
$p'''_c = \dfrac{FL_{hc}}{0.8d_o^2L_t} = \dfrac{52{,}119 \times (87.5 \times 12)}{0.8(11 \times 12)^2 \times 0.625} = 6{,}281$ *lb. per sq. in.*

Stack is safe.

11. *Pull along guy* $= \dfrac{\textit{horizontal pull}}{\sin 55°} = \dfrac{18{,}000}{0.819} = 22{,}000$ *lb. or* 11 *tons.* $\frac{7}{8}$*-in.* rope is required. Add 5,000 *lb.* for initial tension of $\frac{7}{8}$ *in.* guy. *Total force along guy* = 22,000 + 5,000 = 27,000 *lb.* Guy required is 1 *in. diam.*

12. $L_t = 4 + 0.05d_i + 0.0005L_h = 4 + 0.05\,(132) + 0.0005\,(2{,}700) =$ 11.95 *in.* Practical thickness = $1\frac{1}{2}$ *bricks* + $\frac{1}{2}$ *in. mortar joint* = $12\frac{1}{2}$ *in.*

INDEX

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Date Due

MAR 16 '64 ML	MAR 7 '[illegible]		
MAR - 3 '67 [illegible]			
	APR [illegible]		
	APR 1 1 '6[illegible]		
MAY 1 5 1990	APR 2 7 1990		

85

[redacted]